THE UNIVERSITY OF ALBERTA

CHEMICAL AND HYDROLOGICAL SIMULATION OF PRAIRIE LAKE-WATERSHED SYSTEMS

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

GEOLOGY

EDMONTON, ALBERTA

FALL, 1979

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled CHEMICAL AND HYDROLOGICAL SIMULATION OF PRAIRIE LAKE-WATERSHED SYSTEMS submitted by Allan Crowe in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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ABSTRACT

A practical lumped response watershed model has been developed to study lake-watershed systems in a Canadian prairie setting. The model is designed to utilize basic climatic, hydrological and physical data, such as is normally available for lake studies, in order to simulate variations in lake water quality and quantity.

The model has been used to examine the role that climatic, hydrological and physical variables play in controlling the hydrology and chemistry of prairie lakes. These analyses indicated that climatic parameters, such as precipitation, evaporation and temperature play a dominant role in influencing lake levels and salinity of shallow lakes and lakes situated in small watersheds. Large deep lakes or those located in a large watershed are primarily controlled by groundwater discharge and surface runoff. Physically altering the watershed may also produce significant changes to the lake chemistry and surface elevations.

The practical applicability of the model is demonstrated by applying it to a study of Baptiste Lake, Alberta, Canada, where a favourable comparision is achieved between the real and simulated hydrochemical and lake level patterns. The model was primarily used to illustrate the importance of groundwater outflow to Baptiste Lake; indicating that groundwater constitutes a significant proportion of all recharge to the lake.

ACKNOWLEDGEMENTS

The assistance provided by various people in the preparation of this thesisis gratefully acknowledged. Dr. F.W. Schwartz, as the thesis supervisor, provided much help, guidence and encouragement in the development of the model and the finalization of the thesis. I benefitted particularly from various discussions with D.E. McNaughton of MLM Groundwater Engineering, and W.A. Milne-Holme of the University of Alberta

Members of Alberta Environment also contributed to the project. D.O. Trew, D.J. Beliveau and E.I. Yonge of the Pollution Control Division, which initiated the study of Baptiste Lake, kindly provided most of the existing data. The Groundwater Branch, Earth Sciences Division, provided much finacial support for the study. The excellent drafting by Carlos Parraguez and Heidi Osterbauer is appreciated.

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LIST OF SYMBOLS

Symbol	Description
A	area of the lake
$c_0 \rightarrow c_3$	groundwater routing coefficients
C	chemical quality of the lake
C_i	chemical quality of water sources
D	ice thickness
D_1	ice formed during the first winter month
D_l	ice formed during later winter months
E	actual evaporation
E_p	potential evaporation
h	heat transfer coefficient
H	specific heat of ice or snow
i	subscript used to designate ice
I	percolation (infiltration)
k	thermal conductivity of ice or snow
k_i	thermal conductivity of ice
k_s	thermal conductivity of snow
K	storage delay time for a groundwater storage element
K_L	storage delay time for the lake
L_i	heat of fusion of ice
n	subscript used to designate a finite difference node
P	precipitation
q	outflow from a groundwater storage element
Q_{g_n}	total groundwater outflow from a storage element
$Q_{g_{n-}}$	portion of groundwater outflow from a storage element discharged to a given place

Q_l : volume of flow of water

Q_i : runoff from impervious areas

Q_o : surface water outflow from the lake

Q_s : surface runoff

Q_t : volume of groundwater outflow during time step t

Q_{t-1}: volume of groundwater outflow during the previous time step

R_e : proportion of recharge allocated to a groundwater storage element

R_{gw}: recharge to the groundwater zone from the unsaturated zone

R_{gwmf}: maximum allowable groundwater recharge

R_{lz} : total available recharge to the lower unsaturated zone

R'_{lz} : actual amount of water recharged to the lower unsaturated zone that remains in storage here

R_t : recharge to a groundwater storage element over over time step t

R_{t-1}: previous recharge to the groundwater storage element

R_{uz} : total available recharge to the upper unsaturated zone

R'_{uz} : actual amount of water recharged to the upper unsaturated zone that remains in storage here

$_s$: subscript used to designate snow

S : water storage in a groundwater storage element

S_{lzm} : maximum lower unsaturated zone moisture storage

S_t : total groundwater storage in an element over time step t

S_{t-1}: previous groundwater storage in the element

S_{uzm}: maximum upper unsaturated zone moisture storage

S : lake stage

t : time step subscript

t_0 : time at which ice commences to form

T_a : air temperature

T_f : temperature at freezing point

T_m : mean monthly air temperature

T_n : temperature at finite difference node n

T_i : temperature of ice surface

T : duration of uniform recharge to a groundwater storage element

T_l : time of uniform recharge to the lake

V_o: volume of water in the lake above surface water outflow elevation

V: lake capacity

δ : proportion of basin surface represented by a groundwater storage element

γ : proportion of the watershed which is impervious

ϕ : fraction of discharge from a groundwater storage element

ρ_i : density of ice

ρ_s : density of snow

Δt : size of time step

Δx: vertical spacing between finite difference nodes

Δx_i: vertical spacing between finite difference nodes in ice

Δx_s: vertical spacing between finite difference nodes in snow

ϕ : heat exchange factor for calculating potential evaporation

Ψ: daylight and latitude correction factor for calculating potential evaporation

I. INTRODUCTION

Statement of Thesis

Hydrological studies of lake-watershed systems have concentrated typically on quantifying the balance between precipitation, evaporation, surface runoff, groundwater inflow and outflow and lake discharge. Although the contribution of components other than groundwater to the water balance are obtained through standard measurement methods, in most cases groundwater inflow and outflow have been unknown quantities and their significance in the water budget has been speculative.

In practice, the groundwater contribution to lakes is often assumed to be negligible because accurate methods to calculate groundwater recharge and discharge are not available. However, there are increasing indications that suggest that groundwater contributions to stream and lake systems may be considerable (summarized in Schwartz, 1979). An important research priority is, therefore, the development of methods that consider the groundwater component and that are capable of determining how significant groundwater is in the hydrologic balance of a lake-watershed.

The first objective of this thesis is to develop a practical hydrologic model that is oriented primarily to lakes. It is designed to utilize basic climatic and hydrological data in order to predict variations in lake water quality and quantity. A second objective is to use the

model to examine the role that various climatic and watershed variables, such as precipitation, evaporation, surface runoff, groundwater and seasonal climate changes, play in controlling the physical and chemical hydrology of lakes in a prairie setting. The final objective is to demonstrate the practical applicability of the model in evaluating an actual lake-watershed system. The model will be used specifically to estimate the groundwater contribution to Baptiste Lake, Alberta, and to determine the impact that further cottage development may have on the quality of the lake.

Baptiste Lake has been selected for study because there are ongoing government programs concerned with this lake and because there is a large existing data base. The Water Quality Control Branch, Pollution Control Division of Alberta Environment are establishing background limnological data for Baptiste Lake, are defining the extent and sources of pollution in the lake and are assessing the potential impact of a proposed cottage development (Water Quality Control Branch, 1977). The Earth Sciences Division of Alberta Environment was approached by the Pollution Control Division to assist in determining the quantity and quality of groundwater entering the lake. The study of Baptiste Lake is an extension of the field work and the preliminary analysis of those data carried out by the author and incorporated in a report by Trew et al. (1979).

Each of the three objectives will be addressed in

successive chapters of the thesis. The development and theory of the watershed model is presented in Chapter II. Chapter III examines, via sensitivity analyses, the role that the previously mentioned physical parameters have on lake hydrology. Chapter IV discusses the practical application of this model to Baptiste Lake.

Background

Models can be used to analyse and investigate natural processes, predict future changes in a system and study the importance of various components of the system. Those designed for implementation by computers are especially useful because they can handle enormous volumes of data and account for a variety of interactions in complex systems.

Modelling has become a very important tool in the analysis of watersheds. Experience in a variety of disciplines has shown that predictive mathematical models need not be based on an exact mathematical description of the detailed processes involved. This approach to modelling water movement in the hydrologic cycle ignores the mechanics of the system. These so called lumped system models consider the system to be modelled as a single unit. Lumped models used in hydrology have all initially been developed from the same basic and simple water budget equation:

$$\text{OUTFLOW} = \text{INFLOW} \pm \text{CHANGE IN STORAGE} \qquad \ldots\ldots(1)$$

The initial developments in hydrologic modelling were water budget calculations based on a simple accounting of moisture input, outflow and storage. These calculations primarily require precipitation and temperature as input. Occasionaly other climatic data such as dew point, temperature, humidity, solar radiation, wind speed and geographical data such as soils and vegetations are used. Examples of the application of these methods to study water-balances of prairie lakes are given by Laycock (1968, 1971, 1973), Saskatchewan Nelson Basin Board (1972) and Prairie Province Water Board (1952). The drawback of these models is that they represent only a crude long term accounting of water in the hydrologic cycle. Without routing water through a more realistic representation of a watershed, the temporal variability in processes such as evaporation and groundwater discharge, cannot accurately be assessed.

Commencing in the early 1960's modelling progressed towards simulating the hydrologic cycle by routing water through storage units which represent components of the watershed. The watershed is simulated either as a single lumped unit or as a set of lumped models which has the watershed divided into smaller sub-areas. Representation of a watershed by a lumped model is illustrated on Figure 1 and Figure 2.

The first total watershed response model that simulated

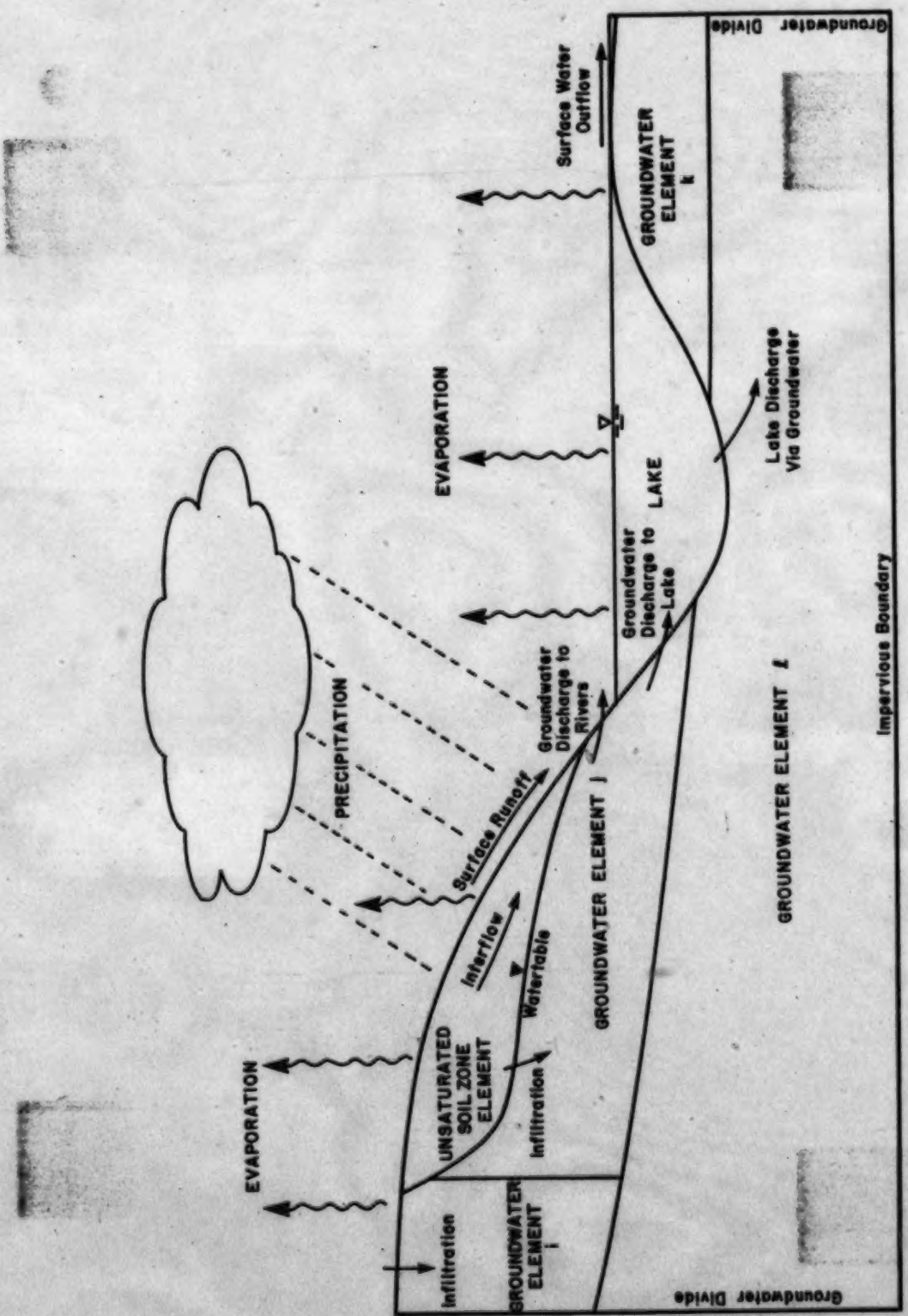


Figure 1. Lumped element representation of a watershed.

the hydrological cycle was the Stanford Watershed Model (Crawford and Linsley, 1966). While this model was designed for streams, the requirements of a hydrological model that they advanced can readily be applied to a lake-watershed:

1. "The model should represent the hydrologic regimes of a wide variety of streams and rivers with a high order of accuracy.
2. "It should be easily applied to different watersheds with existing hydrologic data.
3. "The model should be physically relevant so that estimates of other useful data in addition to streamflow, such as overland flow or actual evapotranspiration, can be obtained."

The Stanford Watershed Model simulates portions of the hydrological cycle by routing and accounting for all moisture in the basin over a period of time. The model consists of water storage units which represent those components of the real system such as the soil zone or groundwater zone, which act to store water for various time periods. A set of empirical algebraic equations control the movement of water among the storage units. Parameters within these equations are used to characterize features of the watershed such as land surface and soil profile. These parameters are calibrated in order that the model predictions of streamflow will simulate recorded streamflow. The model simulates only the hydrologic components of a watershed, having no provisions for handling water

chemistry. The model has undergone many revisions and improvements since its original conception and these are briefly discussed by Linsley et al. (1975).

Huff (1968) extended the Stanford Watershed Model to simulate the hydrologic transport of selected radioactive aerosols. This was later reprogrammed and is known as the Wisconsin Hydrologic Transport Model (Patterson et al., 1974).

Crawford and Donigian (1973) also developed a transport model based on the Stanford Watershed Model. The model, known as the Pesticide Transport and Runoff Model, simulates the loss of pesticides from agricultural lands by "piggy-backing" the pesticides onto the movement of water and, accounts for alteration, volitization and degradation of the pesticides.

Fields and Watson (1975) used an optimizing procedure with the Wisconsin Hydrologic Transport Model to determine input parameters which lead to the best fit for simulated and observed contamination transport and hydrologic values.

Generally there is little or no indication in the literature of application of these three transport models to lake-watershed systems. In each case, the model was tested on a small stream watershed.

Up to now, hydrological studies of lake systems have relied on more conventional water-balance methods (Laycock, 1968, 1971, 1973; Nursall et al., 1971). Fritz and Krouse (1973), using dissolved sodium and natural stable isotopes

of oxygen and hydrogen (oxygen-18 and deuterium), evaluated the pattern of groundwater inflow to a prairie lake and characterized the evaporitic regime. Schwartz and Gallup (1978) demonstrated how major ions (Ca, Mg, Na, K, HCO_3, SO_4, Cl), can be utilized to determine the relative importance of groundwater recharge and discharge to prairie lakes. However, these studies did not take into account the time-varying changes that occur in a lake-watershed system, such as the flow of water or chemical changes, but simply predicted an average lake chemistry from the contributing components, independent of the time at which the data was collected.

A logical extension of the chemical balance technique lies in the routing of major ions through a prairie lake system over a period of time. Such a model could be a useful tool in understanding the hydrology of a prairie lake-watershed. However, as the above discussions explain, a model need not be complex in order to adequately represent a lake-watershed system. Hence, the lumped response model developed in this thesis is adequate for examining features of lake-watershed systems in a prairie setting.

II. THE MODEL

The model developed in this thesis is a lumped response model, similar in purpose and structure to the Stanford Watershed Model and the Pesticide Transport Runoff Model. It is capable of simulating the hydrologic responses of a lake-watershed system to variations in precipitation, potential evaporation and air temperature. The uniqueness of this model exists in the fact that both the hydrologic and mass transport functions are much simpler and much less input data are required. This model is designed to operate with only a basic set of input data. In this respect, the data requirements for the model are compatible with the type of information commonly available for lake systems in Alberta.

The model operates by routing water through an idealized lake-watershed over a period of time. At each time step, water flow through the various storage units and the lake is determined. Derived values such as lake stage, are calculated from given sets of precipitation and potential evaporation data. Information on air temperature is used to simulate hydrologic conditions during winter, such as restricted infiltration, ice formation on the lake, and snow melt in the spring.

Mass, in the form of ions, is also cycled. Each major source of water that flows to the lake is characterized by a

chemical parameter such as total dissolved solids or ionic composition. These sources are precipitation falling directly on the lake, runoff from impervious areas, surface runoff or overland flow and groundwater discharge. The chemistry of the lake water is a mixture of all the water sources modified by processes such as evaporation or ice formation.

The hydrologic components of the model and the flow of water among them are shown in detail in Figure 2. Precipitation is assumed to be rain if the temperature is above 0°C, or snow at, or below 0°C. Snow does not enter the system immediately during the winter, but is stored until spring when it is allowed to melt. The difference between precipitation and potential evaporation represents water that may infiltrate into the unsaturated zone, directly to the groundwater zone, or move overland to the lake via rivers.

Melted snow or rain which falls on the impervious area is added directly to the lake. Impervious areas could, for example, be comprised of streams, rivers, lakes or urban areas with storm sewers and roads, where precipitation is transported directly to surface waters. Runoff from impervious areas must be discharged directly to the lake or a stream before the land can be defined as an impervious area. As is usually the case, all runoff from some buildings and roads, etc. must flow over pervious areas before reaching surface waters and hence, in this thesis, these are

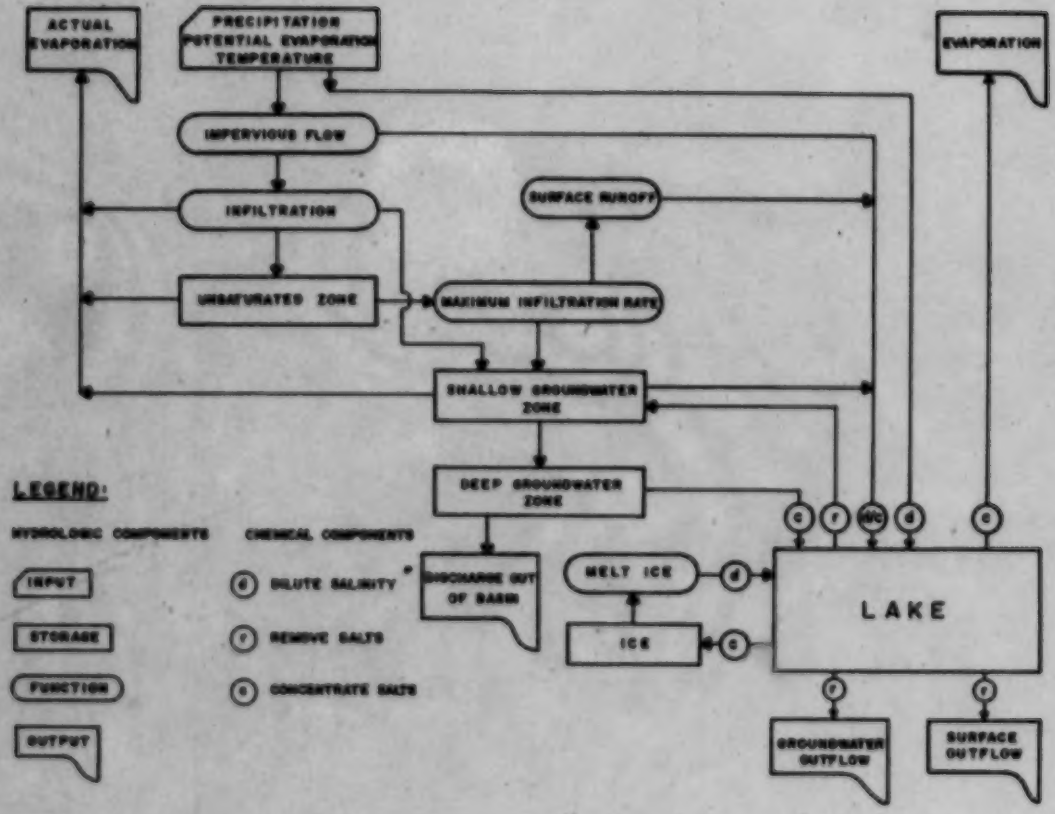


Figure 2. Model flow chart.

not included as impervious areas.

The unsaturated zone is a moisture storage unit overlying the water table. It is characterized by a definite moisture capacity which must be exceeded before recharge can take place to the groundwater zone. Any water in excess of the unsaturated zone moisture capacity is available for recharge to groundwater storage units. However, the rate of recharge is fixed. Potential recharge in excess of this amount will flow to surface waters as overland flow. Following the procedure described by Ayers (1970), surface runoff is defined as the amount of water available for infiltration that is in excess of the water retained in the upper and lower unsaturated zones and the maximum allowable recharge to the groundwater zone.

The groundwater zone is composed of a set of groundwater storage elements or units which are defined with characteristics resembling actual hydrostratigraphic units. Waters from these units may flow directly to the surface water system or to other groundwater storage elements. Groundwater recharge to, and discharge from the storage elements is calculated according to a set of routing equations defined by Dooge (1960).

Rivers are not as fully constructed by the model as they would be in the real hydrologic environment. Only the groundwater discharge component of stream flow is computed with the model. Groundwater, discharged to a river, is a separate parameter because one of the objectives of the

model is to determine how much water directly enters the lake and how much indirectly enters the lake via rivers. It is assumed that all surface runoff and impervious flow will reach the lake whether or not it enters a river, and hence, these two components are routed directly to the lake. River flow can be estimated by summing the calculations of surface runoff, runoff from impervious areas and groundwater discharged to rivers. Water can leave lake storage as surface outflow, groundwater outflow, evaporation or temporarily, as ice in the winter.

Theory of the Model

The Unsaturated Zone

The unsaturated zone is a vital component of a watershed system because it controls the amount of moisture that will recharge the groundwater system. The unsaturated zone also acts as a reservoir, gaining water during periods of precipitation and being depleted during periods of evaporation.

Water is routed through the unsaturated zone to the groundwater units where the water table is not near or at the surface. Otherwise infiltration is assumed to enter groundwater storage directly. The unsaturated zone controls the amount of recharge to the groundwater system in a given period of time. Therefore, the quantity of surface runoff is controlled by characteristics of this zone.

The unsaturated zone (Figure 3), is divided into two parts (Ayers, 1970); an upper unsaturated zone which receives direct infiltration and undergoes evaporation, and a lower unsaturated zone which receives infiltration from the upper unsaturated zone and undergoes evaporation at a reduced rate. Before water flows to the lower unsaturated zone, the moisture storage of the upper zone must be satisfied. Also, before evaporation from the lower zone occurs, all moisture storage in the upper unsaturated zone must be depleted.

Linear units of measurements are utilized by the model for precipitation, potential evaporation, recharge, water storage and discharge. The units are determined as depth over the area of the watershed (eg. cm, m).

Recharge to the unsaturated zone is determined in the following way:

$$R_{uz} = P - E_p \qquad \text{.....(2)}$$

where: R_{uz} = total available recharge to the upper unsaturated zone

P = precipitation

E_p = potential evaporation

Water storage in the upper unsaturated zone is determined by a parameter called the maximum upper unsaturated zone storage capacity. Only when this storage limit is exceeded by infiltration, will there be recharge to the lower zone. Any infiltration, or infiltration combined with moisture already in storage that is in excess of the

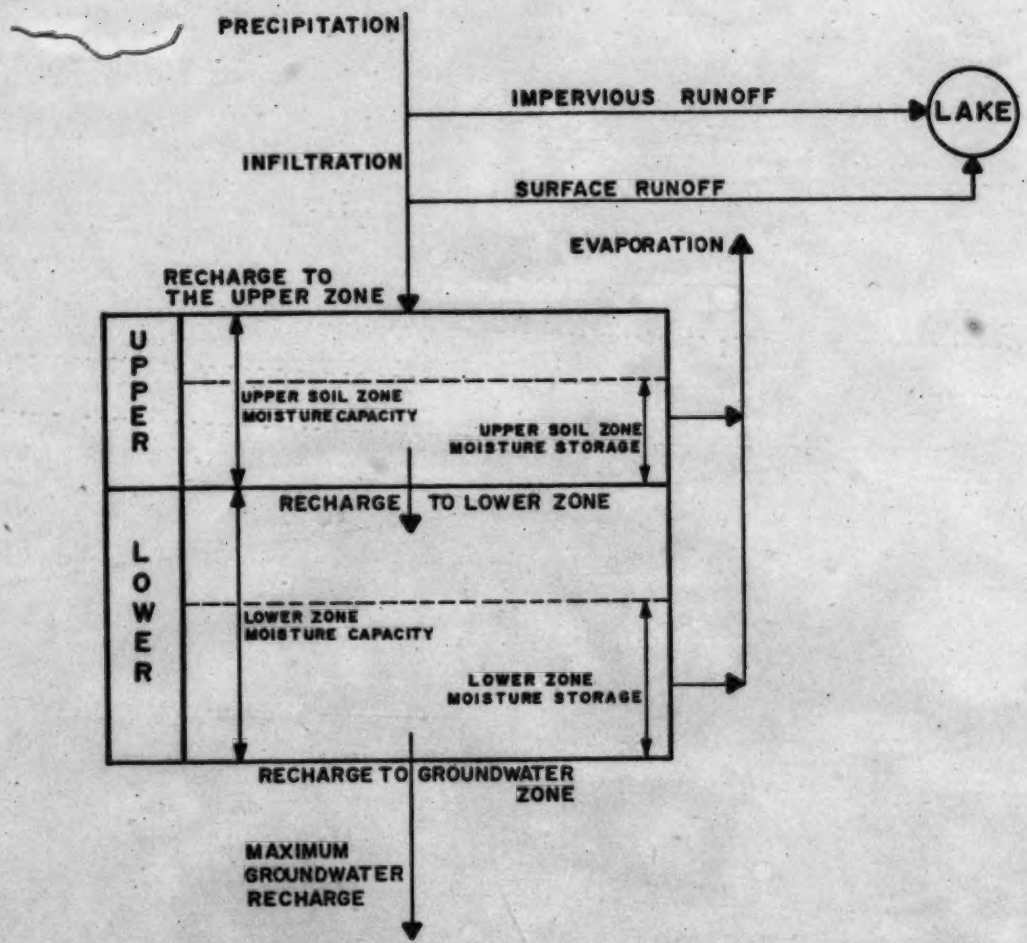


Figure 3. Schematic diagram of the unsaturated zone element.

maximum storage capacity is routed to the lower unsaturated zone according to the relationship:

$$R_{lz} = P - E_p - R'_{uz} \qquad \text{.....(3)}$$

where: R_{lz} = total available recharge to the lower unsaturated zone

R'_{uz} = actual amount of water recharged to the upper zone that remains there in storage

Any moisture in excess of the lower unsaturated zone requirements is routed to the groundwater units using an expression similar to (2) or (3):

$$R_{gw} = P - E_p - R'_{uz} - R'_{lz} \qquad \text{.....(4)}$$

where: R_{gw} = total available recharge to the groundwater zone from the unsaturated zone

R'_{lz} = actual amount of water recharged to the lower zone that remains there in storage

or:

$$R_{gw} = 0 \quad \text{, if (4) } < 0 \qquad \text{.....(5)}$$

From (2) it is evident that evaporation may exceed infiltration. In this case, the present water storage in the upper unsaturated zone is reduced by the amount of excess evaporation. If the evaporation requirements are not satisfied (i.e. $R_{lz} < 0$), then evaporation, defined by the following equation, takes place at a reduced rate from the lower unsaturated zone:

$$E = \left(S_{lzm} / S_{lz}\right) \cdot R_{lz} \qquad \text{.....(6)}$$

where: E = actual amount of water evaporated from the lower unsaturated zone

S_{lz} = maximum lower unsaturated zone moisture storage

S_{lzm} = present moisture content of lower unsaturated zone

No evaporation is allowed from the groundwater units which are overlain by an unsaturated zone, even if evaporation requirements are not met in the unsaturated zone (i.e. R_{gw} cannot be less than zero).

After the moisture requirements of the unsaturated zone have been satisfied and the maximum recharge allocated to the groundwater zone, any water surplus is discharged as surface runoff. This calculation is made using the following expression:

$$Q_s = R_{gw} - R_{gwm} \qquad \text{.....(7)}$$

where: Q_s = surface runoff

R_{gwm} = maximum allowable recharge to the groundwater zone

or:

$$Q_s = 0 \quad , \text{ if } (7) < 0 \qquad \text{.....(8)}$$

Runoff from impervious areas is routed directly to the lake. The amount of runoff from impervious areas is defined by:

$$Q_i = P \cdot \gamma \qquad \text{.....(9)}$$

where: Q_i = runoff from impervious areas

γ = proportion of basin which is impervious

If such areas are present in the basin, then infiltration to the unsaturated zone is reduced by:

$$I = P - Q_1 \qquad \text{.....(10)}$$

where: I = infiltration to the unsaturated zone

The term I replaces P in equations (2), (3) and (4).

The model was designed to simulate hydrologic conditions during the winter, as well as during the summer. Before the unsaturated zone section of the model is reached, a check is made in the program to determine if it is winter. During winter, there will be no infiltration to the unsaturated zone and precipitation is stored on the surface as snow. During the first month in which the average monthly temperature is above 0°C, the snow melts and this moisture is added to precipitation in (10).

Groundwater Storage Elements

Dooge (1960) proposes that a groundwater system can be represented by one or more linear storage units or elements. When these are properly linked together, they provide an adequate basis for predicting groundwater outflow when groundwater recharge is known. Practice has demonstrated that this simple system of linear storage elements, can successfully model a real groundwater system (Dooge, 1960; Ayers, 1970). Input or recharge to an element can occur from three possible sources: infiltrating precipitation, groundwater routed from another element, or from a surface

source such as a stream or a lake. Groundwater outflow is routed to other storage elements, to a surface water body, or to the atmosphere by evaporation.

Dooge (1960) describes four types of groundwater storage elements. The behavior of each element is characterized by the following set of parameters: storage delay time, recharge time and recharge characteristics. The constraints placed on the groundwater storage elements and the terminology used in this thesis has been modified and simplified from Dooge (1960). In this thesis elements are defined as follows:

1. a shallow groundwater element, which underlies an unsaturated zone,
2. a shallow groundwater element which has no overlying unsaturated zone,
3. a deep groundwater element,
4. a composite groundwater element.

Shallow groundwater storage elements gain water from precipitation. Type 1 elements are overlain by an unsaturated zone through which precipitation infiltates to the groundwater system and from which water evaporates. Hence, no water will evaporate from the Type 1 elements.

Before there is any groundwater recharge, the water storage requirement of the unsatuated zone must first be fulfilled. In a case where the water table is located at or very near to the ground surface, precipitation and evaporation is assumed to occur directly from the Type 2

groundwater storage element.

Groundwater discharge from the shallow storage elements may be routed either to other elements or discharged directly to surface water bodies. It is also possible for water to flow from a surface water body into the groundwater storage element. For example, during a period of sudden rise in the level of a river or a lake surface, water will flow into the bank. This situation is assumed to apply only to the two shallow groundwater storage elements.

Recharge to the deep groundwater storage element, Type 3, can only come from other elements (either shallow, deep or composite). In addition, it is assumed that evaporation cannot take place from these deeper elements. Discharge from the deep groundwater element is routed to other storage elements or a body of surface water.

The Type 4 element has the properties of both the shallow and deep groundwater elements. It can act like a shallow element with discharge by outflow and evaporation. Once the storage is depleted to a minimum limit, the element assumes properties of a deep element, discharging by outflow only. The physical counterpart of this type of storage element is a hydrostratigraphic unit where groundwater undergoes evaporation until the water table is lowered to a level where evaporation no longer removes water. Further depletion to lower the water table will only occur via groundwater outflow.

Figure 4 schematically illustrates a typical

groundwater storage element. Water discharging from an element is allocated to various recipients. The figure shows all possible sources of recharge and all possible recipients of discharge. Each of the four types of elements will actually use only part of these components.

As previously discussed, only shallow groundwater storage elements can be recharged by water leaving the unsaturated zone. The quantity of recharge depends on the proportion of the basin surface area occupied by the storage element as follows:

$R_e = \delta \cdot R_{gw}$ if an unsaturated zone is present .....(11)

or:

$R_e = \delta \cdot I$ with no unsaturated zone .....(12)

where: R_e = proportion of recharge allocated to an element

δ = proportion of area represented by a groundwater storage element

I = percolation to the groundwater zone

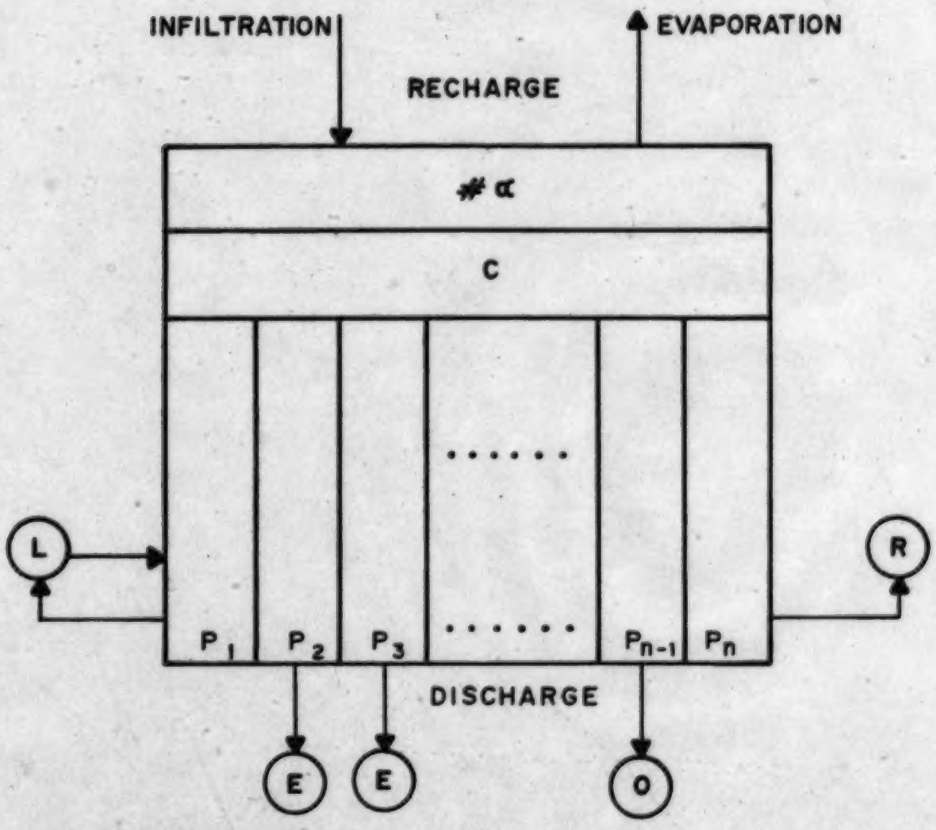
Groundwater discharges to other elements, rivers or directly to the lake. The outflow is proportionally divided according to:

$$Q_{gw} = Q'_{gw} \cdot \phi \qquad \text{.....(13)}$$

where: Q_{gw} = proportion of outflow from an element discharging to a given place

Q'_{gw} = total outflow from an element

ϕ = proportionality factor



LEGEND:

α	ELEMENT NUMBER
C	GROUNDWATER SALINITY (mg/ℓ)
P-1 ··· Pn	PROPORTION OF OUTFLOW FROM ELEMENT
(L)	LAKE
(E)	ANOTHER STORAGE ELEMENT
(R)	RIVER
(O)	OUT OF BASIN

Figure 4. Schematic diagram of a typical groundwater storage element.

As previously noted, evaporation may occur from a Type 2 shallow groundwater element. The amount of evaporation is determined by a negative value of infiltration as determined by equation (10). The negative value of infiltration is then inserted into equation (12), indicating a net loss of water.

Groundwater Routing Equations

Storage in an element is not described by a simple balance relationship (for example, in equation (1)), but is controlled by a parameter termed the storage delay time. Hence, storage in an element is defined by:

$$S = K \cdot q \qquad \text{.....(14)}$$

where: S = storage in an element

q = outflow from an element

K = storage delay time

This relationship assumes that the time periods in which recharge occurs are equal and that the rate of recharge in the time period is constant.

Dooge (1960) developed mathematical expressions to describe the discharge of groundwater from a linear storage element and to calculate the amount of storage remaining in an element. Once the volume of recharge to the storage element and the routing coefficients are known, the following equations hold:

$$Q_t = c_0 R_t + c_1 R_{t-1} + c_2 Q_{t-1} \qquad \text{.....(15)}$$

$$S_t = c_3 R_t + c_4 Q_t \qquad \text{.....(16)}$$

where: Q_t = volume of outflow during time step

Q_{t-1} = volume of outflow during the previous time step

R_t = volume of recharge over time step

R_{t-1} = volume of recharge during the previous time step

S_t = total storage at the end of time

c_0, c_1, c_2, c_3, c_4 = routing coefficients

The routing coeffecients are dependent only on values of storage delay time and time for recharge to an element. The routing coefficients are defined as:

$$c_0 = 1 - \frac{K}{T}\left(1 - e^{-I/K}\right) \qquad \text{.....(17)}$$

$$c_1 = \frac{K}{T}\left(1 - e^{-I/K}\right) - e^{-I/K} \qquad \text{.....(18)}$$

$$c_2 = e^{-I/K} \qquad \text{.....(19)}$$

$$c_3 = \frac{K}{T} - \frac{1}{e^{I/K} - 1} \qquad \text{.....(20)}$$

$$c_4 = \frac{1}{e^{-I/K} - 1} \qquad \text{.....(21)}$$

where: K = storage delay time of an element

T = duration of uniform recharge to an element

Discharge from an element declines exponentially and recharge increases exponentially (Figure 5). The reader is

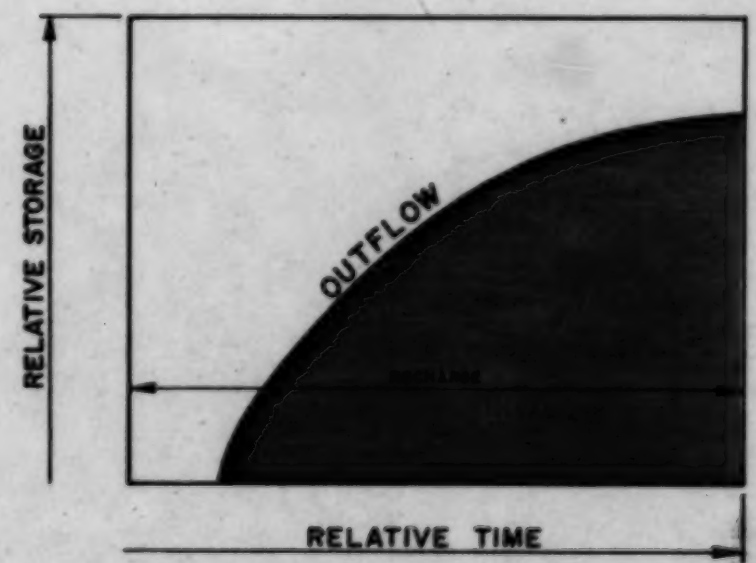


Figure 5. Groundwater outflow from, and storage in a groundwater element.

referred to Dooge (1960) for a complete mathematical development of these routing coefficients. Also, because of the time delay factor, recharge to an element may be occurring but the discharge continues to be dominant, indicating a net loss of storage.

Should a shallow element that is adjacent to a body of surface water experience excessive evaporation, the storage in the element will drop to zero, after which further water requirements for evaporation will be satisfied by flow from surface waters to the storage element. During this time only enough water to fulfill the evaporation requirements will be obtained from the surface water body and hence, storage in the element remains at zero.

If recharge from a body of surface water is not allowed but evaporation takes place, groundwater discharge will continue until storage is zero, at which time both the storage and outflow will remain at zero until the storage element is recharged. However, zero storage is usually attained during the time interval rather than at the end of the time interval. The following equation (Dooge, 1960) provides an adjustment to the discharge calculated in equation (15) to allow for outflow during only part of the time period:

$$Q_t = c_5 S_{t-1} \qquad \ldots\ldots (22)$$

where: S_{t-1} = storage in element during the previous time interval

Q_t = adjusted outflow from the storage

element for part of time step
when evaporation is occurring

c_5 = routing coefficient defined as:

$$c_5 = 1 - \frac{\log_e(1-A)}{A} \qquad \text{.....(23)}$$

where: $$A = \frac{S_{t-1}}{R_t} \cdot \frac{T}{K} \qquad \text{.....(24)}$$

The Lake System

The climate of the Canadian prairies is characterized by a large variation in temperature and the nature of precipitation, which affects the hydrology of a lake. It is important for a hydrologic model to account for these climatic conditions in order that water is routed through the hydrologic elements properly.

In this model, a year is divided into three climatic divisions. Defined primarily on the basis of average monthly temperature, they are:

winter months: average monthly temperatures are less than 0°C.

spring month: first month following winter which has a temperature greater than 0°C.

summer months: months between spring with temperatures above 0°C.

During summer months, the sources of water for the lake are surface runoff, runoff from impervious areas, river

flow, groundwater discharge and precipitation falling on the lake. Water is lost from the lake by evaporation, surface outflow and discharge via groundwater flow.

In winter, only groundwater and river flow are assumed to add water to the lake. Snow accumulates and is not free to infiltrate or runoff over the land surface. It is assumed that, during the winter, water does not evaporate from the lake, the ice or the snow pack and that all snow falling on the the ice remains until spring. Water temperature is assumed to decline to 0°C during the initial half of the first winter month because air temperatures are usually colder than water temperature during the fall. During this time, evaporation takes place from the lake but there is no surface runoff or infiltration.

All components of recharge and discharge that exist in a summer month are assumed to be active in the spring. At this time, the snow on the watershed, and ice and snow on the lake are assumed to melt. Two assumptions are made for the spring month: (1) all ice and snow has melted by the end of this month and, (2) the ground thaws rapidly during the spring, allowing water to infiltrate to the unsaturated and groundwater zones. These assumptions are stated primarily to simplify the model and are justified because the large time step that is used by the model would cover the actual date of snow melt and thawing of the ground.

Two pathways of outflow from the lake are via the surface and subsurface. Surface water outflow is calculated

in the model from the volume of lake water above the surface water outlet elevation. A capacity-discharge curve function for the lake should normally be provided by the model user (discussed in the following Operation of Model section). Outflow via groundwater is simply removed from the calculations rather than by moving through groundwater storage elements. The quantity of groundwater is calculated by a defined depth of water loss from the lake times the area of the lake.

Ice Formation

The formation of ice is an important process in lakes of the Canadian prairies. Its importance is evident when one considers that lakes are often covered with ice from November to April, and that a large proportion of the total water volume of the lake may be frozen. One major result of ice formation is partitioning of ions between the unfrozen lake water and ice. The net effect is for the ions to become concentrated in the unfrozen water. Therefore, an ice forming component in the model is essential for a rigorous description of the behaviour of lakes in a prairie setting during winter.

A simple expression describing the formation of ice, assuming that the temperature gradient is uniform through the ice, is the Stefan Equation (Fertuck et al., 1970; Ingersoll et al., 1948; and Pounder, 1965):

$$D^2 = \frac{2k_i}{L_i t_0 \rho_i} \int_{t_0}^{t} (T_f - T_i)\,dt \qquad \text{.....(25)}$$

where: D = ice thickness

k_i = thermal conductivity of ice

ρ_i = ice density

L_i = heat of fusion of ice

T_f = temperature at freezing point

T_i = temperature of ice surface

t_0 = time at which ice formation commences

t = time at which ice thickness is calculated

Equation (25) cannot be directly applied to formation of ice on lakes because most often air temperature is only available, while the temperature of the surface of the ice is actually required. Direct substitution of air temperatures in equation (25) will not produce accurate results because snow on the ice is an insulator, resulting in a considerable difference between air and ice surface temperatures.

Pertuck et al. (1970) discussed a one-dimensional finite difference model for the freezing of ice under a cover of snow given only air temperature, wind speed and the depth of snow on the ice. In their representation of the Stefan Equation, the temperature at any point in the ice or snow is calculated by (ρ_i, H, k, L_i are assumed to be constant):

$$T_{n,t+1} = \frac{T_{n-1,t} + (M-2)\cdot T_{n,t} + T_{n+1,t}}{M} \qquad \text{.....(26)}$$

where: $T_{n,t}$ = temperature at a finite difference node

n = subscript used to designate the finite difference node

$$M = \frac{\rho H \Delta x^2}{k \Delta t} \qquad \text{.....(27)}$$

H = specific heat of ice or snow

k = thermal conductivity of ice or snow

Δx = vertical distance between nodes

Δt = time step

The temperature of the snow at the snow-ice interface is determined by choosing Δx of the snow so that:

$$\frac{k_s}{\Delta x_s}\left(T_{n-1,t} - T_{n,t}\right) = \frac{k_i}{\Delta x_i}\left(T_{n,t} - T_{n+1,t}\right) \qquad \text{.....(28)}$$

where: k_s = thermal conductivity of snow

Δx_s = vertical spacing of nodes in the snow

Δx_i = vertical spacing of nodes in the ice

and the temperature at the snow-air interface (set Δt in equation (27) so that $M = 2$) is:

$$T_{1,t} = \frac{T_{2,t} + N\cdot T_{a,t}}{1+N} \qquad \text{.....(29)}$$

where: $T_{a,t}$ = air temperature

$$N = \frac{h \Delta x}{k_s} \qquad \text{.....(30)}$$

h = heat transfer coefficient

This formulation has been simplified because the watershed model requires only an approximation solution to ice growth. Only 3 nodal points were defined (as compared to 6 used by Fertuck et al.), with n=1 at the snow-air interface, n=2 at the snow-ice interface and n=3 at ice-water interface. The influence of wind is also neglected. With these simplifications, equation (29) becomes:

$$T_{1,t} = T_{a,t} \qquad \text{.....(31)}$$

and the temperature of the other two nodes are:

$$T_{2,t} = T_{i,t} \qquad \text{.....(32)}$$

$$T_{3,t} = T_{f,t} \qquad \text{.....(33)}$$

where: $T_{i,t}$ = temperature at the ice-snow interface

$T_{f,t}$ = temperature of the freezing point of water (0°C)

Therefore, equation (28) can be rewritten as:

$$T_{i,t} = \frac{\frac{k_s}{\Delta x_s}\left(T_{f,t} - T_{a,t}\right)}{\frac{k_s}{\Delta x_s} + \frac{k_i}{\Delta x_i}} \qquad \text{.....(34)}$$

Equation (34) is substituted in equation (26) to give the ice formation equation:

$$D = \sqrt{\frac{-2T_{i,t}\, k_i\, t}{L_i \rho_i}} \qquad \text{.....(35)}$$

Ice begins forming during the first month in which the average monthly temperature is below 0°C, and continues as long as the temperature remains below 0°C. Ice thicknesses are calculated during this month according to equation (35), assuming there is no snow on the ice; $T_{i,t} = T_{a,t}$. The calculations for the following winter months use equation (35) with $T_{i,t}$ calculated from equation (34).

Snow is allowed to accumulate on the ice. The depth of snow is taken to be 10 times the liquid equivalent of the precipitation. Normally, as time progresses snow will compact and become denser. However, in this model its density remains equivalent to that of fresh snow. It is assumed that a thick layer of snow with a low denisity has the same insulating effect as a thin layer of dense snow. This assumption is based on the fact that the heat conductance is a function of the depth of the snow times its density. As the snow compacts, its depth decreases and its density increases. While the relationship is not linear, it is adequate for a simple ice forming model.

Variables used in the ice forming equations were obtained from Pertuck et al. (1970) because their study area; Saskatoon, Saskatchewan and this one, have similar climatic and geographical settings. Pertinent values are listed on Table I. Substituting the values shown on Table I

into equation (35) will simplify the ice forming equation to:

$$D_1 = \sqrt{225 \cdot T_o} \qquad \text{.....(36)}$$

$$D_f = \sqrt{\frac{\frac{1.729 \times 10^{-4} \cdot T_o}{\Delta x_s}}{\frac{1.729 \times 10^{-4}}{\Delta x_s} + \frac{5.350 \times 10^{-3}}{\Delta x_i}}} \qquad \text{.....(37)}$$

where: D_1 = ice formation during the first winter month

D_f = ice formation during the following winter months

Table 1.

VALUES OF THE ICE FORMING MODEL PARAMETERS

$k_s = 1.729 * 10^{-4}$ cal/sec-cm-°C

$k_i = 5.350 * 10^{-3}$ cal/sec-cm-°C

$\rho_s = 0.100$ gm/cm³

$\frac{k_i}{L_i \rho_i} = 6.276 * 10^{-5}$ cm²/sec-°C (ice with a snow cover)

$\frac{k_i}{L_i \rho_i} = 4.881 * 10^{-5}$ cm²/sec-°C (ice without a snow cover)

All values are from Pertuck et al. (1970), except ρ_s which is from Pounder (1965).

The ice melts during the first month which has an average monthly temperature above 0°C. All ice and snow is melted by the end of this month. This assumption has been substantiated by Pounder (1965) and by observation at Baptiste Lake. Snow is converted to water at a rate of 10 cm of snow being equivalent to 1 cm of water and ice at a ratio of 1:1.

Chemical Transport and Balance

The transport of dissolved constituents through the watershed is based on a simple routing and accounting procedure. Although the model will now only consider one chemical parameter, it could be extended to handle several. Chemical reactions, dissolution, precipitation or stratifying the lake are not included in the model directly. However, because the chemistry of water from each watershed component can be specified, all important chemical processes operating in the basin are directly considered. The chemical quality of the lake water is calculated according to the dilution equation:

$$C = \frac{C_1Q_1 + C_2Q_2 + \ldots + C_iQ_i}{Q_1 + Q_2 + \ldots + Q_i} \qquad \ldots\ldots(38)$$

where: C = concentration of the lake

C_i = concentration of the water sources

Q_i = volume of flow of the water sources

The chemical inputs to the lake originate from precipitation, impervious flow, surface runoff and

groundwater. Calculations of the contributions from the first three are straight forward. The total inflow is the chemical quality of these sources times their respective volumes of water. However, groundwater discharge may originate from several storage elements, each with a different water quality. Groundwater can discharge directly to the lake or to rivers. Rivers also add chemical components to the lake. However, as previously discussed with respect to the discharge of water to rivers, the chemistry of the rivers are not defined but are the same as the groundwater that discharges to them because no surface runoff or precipitation is mixed with this water.

The model can account for the concentration of ions in the lake water by evaporation. It is assumed that no dissolved constituents are lost through the evaporation process or no salts are precipitated as the salinity of the lake increases. This assumption is valid only if the volume of water in the lake is sufficiently large so that evaporation removes only a small portion of lake water.

During the winter, ice will form on the surface of the lake from lake water. As the ice forms, ions are generally excluded from the ice but remain in the lake water, thus increasing the salinity of the lake. Snow, accumulating on the ice, will have the same chemistry as precipitation, but this is not added to the lake until the ice and snow melt during the spring.

Ions are removed from the lake only through natural

flushing due to the outflow of surface water and discharge via groundwater.

Operation of the Computer Program

The model was programed in Fortran IV and run on the AMDAHL 470V/6 computer at the University of Alberta. The program consists of a main program and four subroutines that must be supplied by the model user. A complete listing of the program and user's manual are is provided in Appendices.

The basic sequence of operations involved in the model is shown in Figure 6. The program is designed to continuously loop through the simulated watershed processes using a time steps of one month. S.I. units are used throughout the program.

Some of the input parameters may not be readily attainable from actual field data, but require a trial and error process to determine a set of values for these parameters which will produce an acceptable fit between recorded and simulated watershed responses. A detailed description of the calibration procedure for the model follows.

It should be noted that this model produces an approximation to actual field setting, and an exact correspondence between measured and predicted responses should not be expected. Simulation and calibration runs should continue only until the user is satisfied that a physically reasonable set of model parameters yield

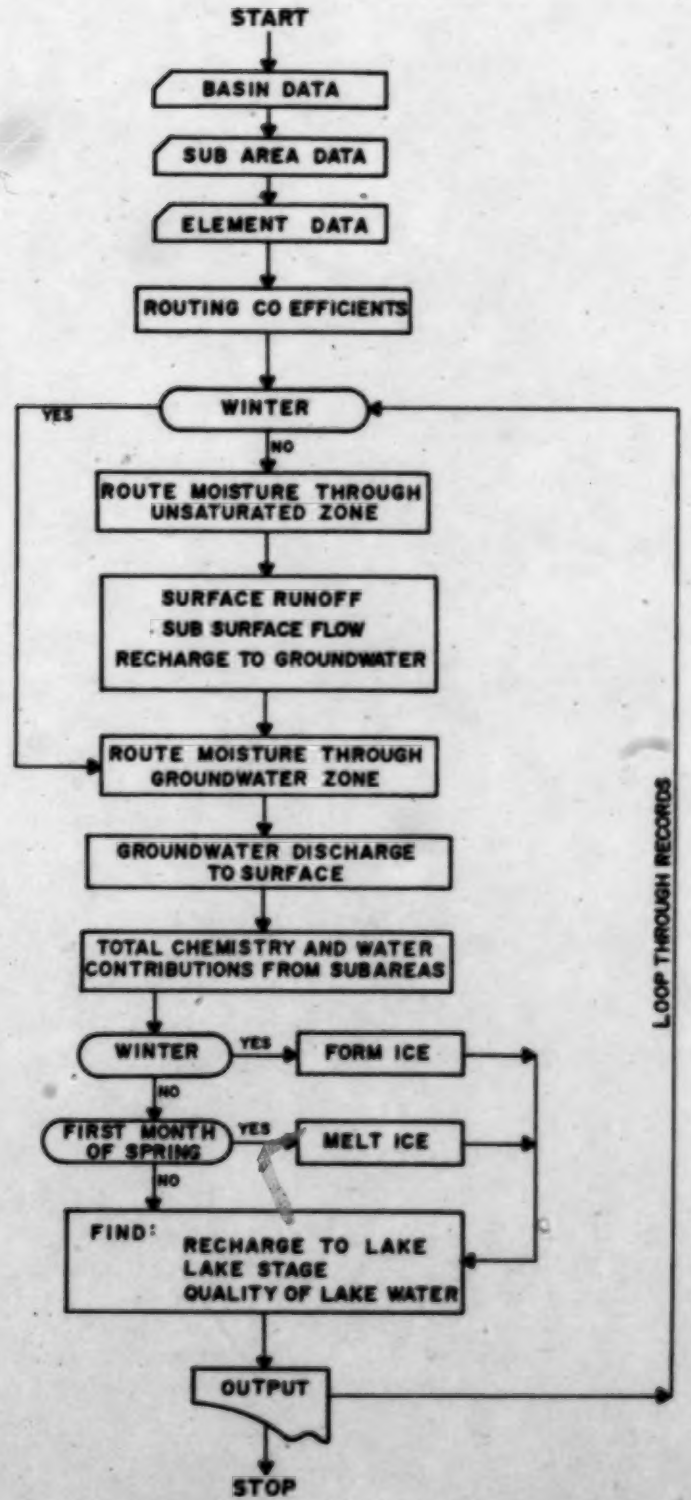


Figure 6. General flow chart of the lake-watershed model.

predictions which are adequate for the particular needs of the study.

User Supplied Functions

Four functions, which determine the physical hydrologic characteristics of the lake, must be supplied by the model user. The data required to determine the functions should be obtained from hydrographic surveys of the lake and rivers. Should the data not exist, reasonable estimates can be made from published information. The functions are:

AREALK : Function used to calculate the area of the lake in km^2, given a lake stage in m.

ELEVLK : Function which finds the lake stage, in meters above datum, given the volume of the lake in m^3.

VOLLK : Function required to calculate the volume of water in the lake, in m^3, given the lake stage in m.

OUTFLO : Function which gives the surface water outflow from the lake, in m^3, given the lake stage.

Input parameters and the calling sequence for the functions are supplied in Appendix I. Examples of the functions are provided at the end the program listing.

Input

Two types of input are required for the program: first, watershed parameters that define the basin and second, climatic variables. The watershed parameters consist of information required to define the physical characteristics

of the lake and watershed, the groundwater storage elements, chemical composition of the various waters and the route taken by the groundwater to reach the lake. The actual parameters arising from this information are defined only once in the model and do not change with time. Watershed parameters can be sub-divided into two groups on the basis of information which can be attained from field measurements and those which cannot. Lake-watershed parameters not obtainable by field measurements require calibration trials to select a value which appear to give the best fit with actual field records. The problems associated with choosing the appropriate values for these parameters is considered in a following section called Calibration.

The second group of input comprise the climatic variables. These are input at each successive time steps. The climatic variables are, precipitation, potential evaporation and air temperature.

A complete description of procedures for preparing the input data and for dimensioning the arrays is presented in Appendix I. A sample input is shown in Appendix III.

A few points should be noted regarding particular input values. Each groundwater element is identified by number. The element numbering should start at 1 and increase sequencially by 1 generally following the routing path taken by the groundwater as it flows through the model. A new set of element numbers, starting at 1, should be provided for each subarea. Figure 7 shows some examples of element

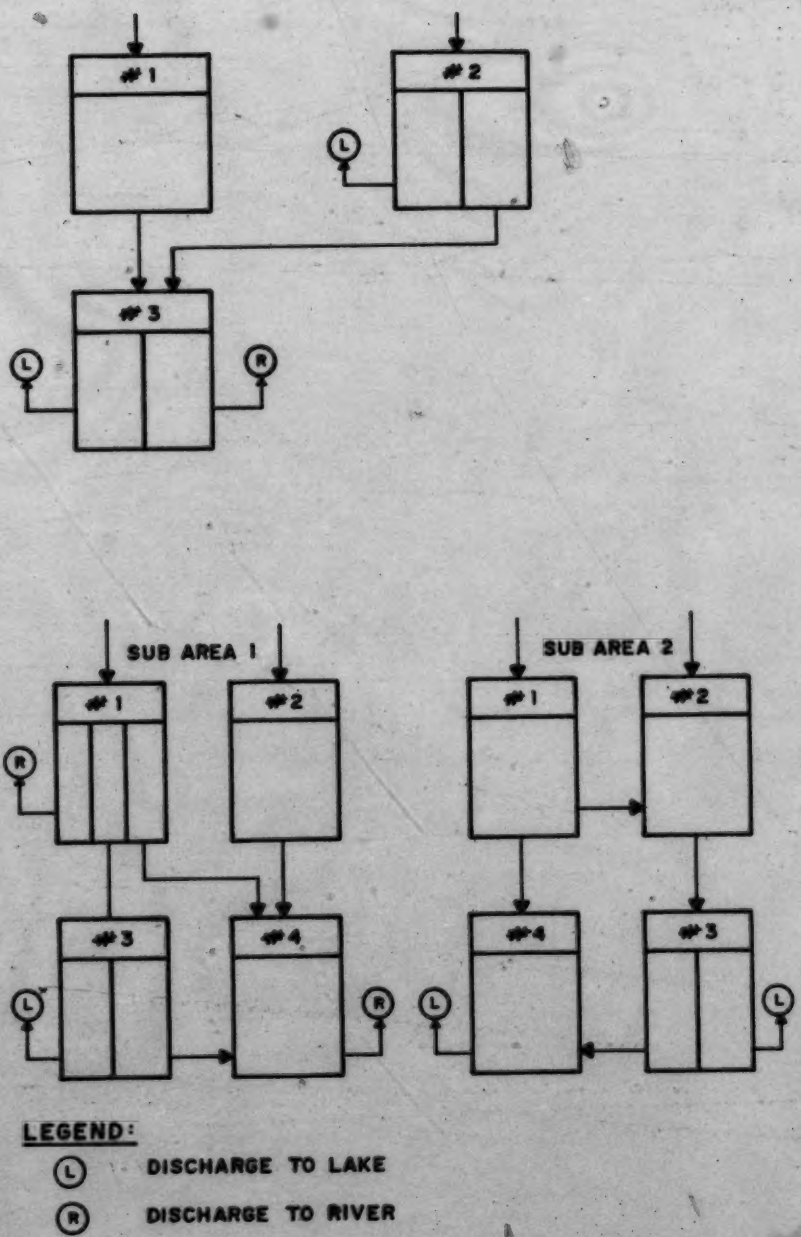


Figure 7. Examples of numbering storage elements.

numbering.

There are four types of groundwater storage elements, each having particular recharge and discharge properties. The type of element is identified, by the model, solely on the basis of input parameters of recharge to the element. Tests to determine if recharge to an element may orfginate from the unsaturated zone or precipitation (REPREC), if evaporation is allowed (NEGREC), and if recharge from a surface water body occurs from an element (NEGQGW), are expressed as 'T' if it is allowed or 'F' if it is not. Hence, a shallow storage element of Type 1 has REPREC = T, NEGREC = F and NEGQGW = T or F. Type 2 elements have REPREC = T, NEGREC = T and NEGQGW = T or F. Deep storage elements are identified by REPREC = F, NEGREC = F and NEGQGW = F.

The proportion of the surface area of the watershed occupied by a shallow groundwater storage element and (PCTAR) the proportion of groundwater outflow from an element allocated to other various storage units (PCTELM) are expressed as decimal fractions. TOELM designates where the discharge from an element is routed. Values from 1 to 89 are reserved for other storage elements, 90 to 98 indicate discharge to rivers and 99 defines output to the lake. The first value of PCTELM and TOELM refers to discharge to the lake and must always be specified even if no discharge occurs from the storage element to the lake. In this case, the first value of PCTELM is 0. and the first value of TOELM is 99.

All parameters and variables used by this model require S.I. units. It is important to keep the units of the input parameters consistant with the definitions given in Appendix I.

Output

Output consists of calculated hydrologic and hydrochemical values and input parameters and variables. All input parameters are printed, providing the user with a check. The following values are printed at the end of each time interval:

1. the record counter,
2. a subarea identifier,
3. air temperature, in °C,
4. precipitation, in cm,
5. potential evaporation, in cm,
6. calculated actual evaporation, in cm (does not include actual evaporation from the groundwater zone),
7. total flow from the impervious portion of each subbasin, in m^3,
8. moisture content of the upper unsaturated zone, in cm,
9. moisture content of the lower unsaturated zone, in cm,
10. recharge to the groundwater zone from the unsaturated zone, in cm,

11. infiltration to the unsaturated zone or groundwater zone with nooverlying unsaturated zone, in cm,
12. groundwater discharge to the lake, in cm,
13. impervious area flow to the lake, in cm,
14. groundwater discharge to the rivers, in cm,
15. quantity of surface runoff to the lake, in cm,
16. total outflow from the lake via groundwater, m^3,
17. the lake stage, in m above a datum,
18. total recharge to the lake, in m^3,
19. total surface water outflow , in m^3,
20. chemical quality of the lake water, in mg/l,
21. ice thickness, in cm.

An Example of output is presented in Appendix IV.

Calibration of the Model

Parameters that are not easily measured in the field, can only be determined by a calibration procedure in which the data are varied systematically from trial to trial to derive a set of optimum values which will best simulate the actual watershed records. In some models this parameter selection procedure is carried out as part of the algorithm (Fields and Watson, 1975). However, in this work, a trial and error slelection process has been utilized. The parameters calibrated are:

PCTIMP: the percentage of the basin which is impervious
QGWP : previous groundwater outflow from an element
RELMP : previous recharge to an groundwater element

USZMAX: maximum moisture content of the upper unsaturated zone

LSZMAX: maximum moisture content of the lower unsaturated zone

USZMP : initial moisture content of the upper unsaturated zone

LSZMP : initial moisture content of the lower unsaturated zone

DT : storage delay time from a groundwater element

RGWM : maximum allowable recharge to the groundwater zone from the unsaturated zone

GWOLK : lake discharge via groundwater

PCTELM: proportion of outflow from an element

While it appears as if there are many parameters that must be calibrated, the problem is simplified because most values lie within a narrow range.

PCTIMP can be established from a topographic map by measuring the area of surface water (excluding the lake) and urban areas with runoff flowing directly to the lake. Because PCTELM has the effect of increasing surface runoff to the lake and hence increasing the level of the lake, some minor adjustments may be required. Generally, the effect of increasing PCTIMP will be to decrease groundwater recharge and discharge to the lake and increase runoff from impervious areas.

QGWP and RELMP are most easily estimated by using as a starting point, a month following a dry period or the winter

where evaporation or groundwater outflow have almost depleted the groundwater storage in the elements. At this time QGWP and RELMP are assumed to be zero. After results from several years of records are available, a better estimate may be obtained by examining groundwater outflow and recharge during the final simulation period for these months.

USZM and LSZM control the amount of moisture retained in the unsaturated zone, which indirectly limits the amount of water that is recharging the lake in the form of groundwater discharge or surface runoff. These are especially influential during the spring when the snow pack is melted and runoff is increased. Throughout the summer in the prairies, it has been shown generally that the moisture capacity of this zone should not allow recharge to the groundwater system unless an unexpectantly long-term or intense rainfall occurs. USZM and LSZM, along with USZMP and LSZMP, can only be determined through a trial and error procedure, but initial values should be between 10 and 15 cm for LSZM + USZM in Alberta (Laycock, 1971). In general, an increasingly larger total unsaturated zone requires more water to satisfy this zone's moisture capacity before moisture can percolate to the groundwater zone, thus delaying the time for recharge to the groundwater zone.

DT, the storage delay time, and RT, the time for recharge to a groundwater element, influence the time and volume of groundwater that is discharged to the lake. In

this model, the time step is one month, so RT is always 1. While the value of DT is usually between 1 and 5, it still must be established by trial and error.

The storage delay time and time for recharge to an element were plotted to illustrate the influence that they have on recharge to, storage in, and discharge from a groundwater storage element. Figure 8 shows a plot of DT:RT

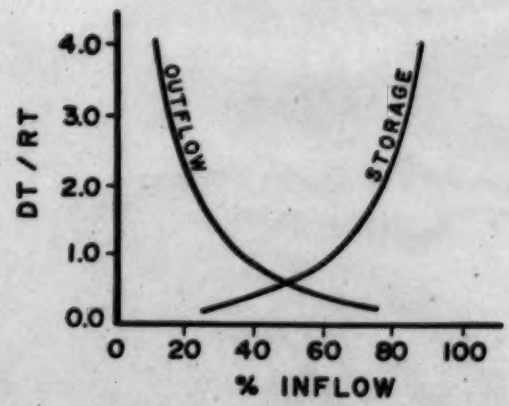


Figure 8. Analysis of groundwater recharge times and discharge times.

versus the percentage of the recharge to an element that is discharged and the volume of water remaining in storage. As DT:RT increases, the rate and total volume of recharge to the lake and the amount of groundwater discharge to the lake will decrease.

Three further parameters, BGWH, GWOLK and PCTELN require calibrating to determine optimum values for simulating the watershed responses. The maximum allowable

recharge to the groundwater, BGWM, should be calibrated by trial and error. The value of BGWM controls groundwater discharge and surface runoff. It is expected to lie between 0 and 5 cm. GWOLK controls the lake level in the calculation of water removed from the lake during each time step. The value should be estimated by trial and error. The proportion of outflow from an element that is discharged (PCTELM), to other elements, rivers or the lake, should first be estimated from the geologic data. Finial adjustments to PCTELM require calibration.

Calibration should initially only involve the water routing components of the model to approximate lake elevation, flow via rivers and discharge of lake water by a surface outlet. Only small adjustments should be required to these parameters during the next few runs to match the water chemistry of the lake and rivers. Because the chemical data from the watershed can be reasonably well determined, the extent of fit afforded the first few simulations may provide a further independent check on the appropriateness of the hydrologic parameters.

It is best to work with long term simulations for two reasons. A longer run provides more varied climatic records to which the model must use in simulating the lake records, giving a better probability of predicting the lake-watershed when variables are unknown or changed. Also, a longer run will reduce the influence of the choice of the intial parameters, such as QGWP, RELMP, lake stage, or lake water

quality on later results. Experience with several data sets show that the initial conditions only inflence the initial 6 or 7 simulation periods.

Verification of the Model

Verification of a model is an integral part of the development. This procedure ensures that the model has no undetected programming or logic errors. In order to gain confidence in this model, it was tested with many representative combinations of input parameters. The testing was carried out to ensure that any possible set of climatic data, unsaturated zone moisture conditions and groundwater element parameters could be correctly handled by the model.

The model was also verified by comparing calculated results with three sets of published records. The procedure which routes moisture through the unsaturated zone was tested with Ayers' (1970) precipitation, potential evaporation and unsaturated zone moisture storage data. The values computed by this model duplicated the values calculated by Ayers (1970). Routing of moisture through the groundwater zone was verified by comparing the model's calculations, with results presented by Dooge (1960) for a set of test data. The values computed by the model were the same as the calculations that appeared not to be in error. In both Ayers' (1970) and Dooge's (1960) papers, some errors were found in the data and calculations. The correspondence between their calculations and the model's indicates that

the errors in Ayers (1970) and Dooge (1960) were not significant in the calculations and probably resulted from printing. The ice forming model was checked with data from Fertuck et al. (1970) and ice measurements obtained at Baptiste Lake. The calculated values compare favorably to the measured ice thickness. Results are listed in Table 2.

Table 2.

VERIFICATION OF THE ICE FORMING MODEL

Data from Fertuck et al. (1970)

	ice thickness (actual)	ice thickness (model)	precip.	temp.
Dec:	50 cm	64.7 cm	1.47 cm	-16.4 °C
Jan:	80 cm	89.6 cm	4.17 cm	-27.8 °C
Feb:	92 cm	105.4 cm	1.58 cm	-15.9 °C

Data from Baptiste Lake

	ice thickness (actual)	ice thickness (model)	precip.	temp.
Nov:	? cm	22.9 cm	0.56 cm	-2.06 °C
Dec:	32 cm	33.1 cm	4.24 cm	-10.61 °C
Jan:	43 cm	42.6 cm	1.86 cm	-14.40 °C
Feb:	51 cm	45.0 cm	0.89 cm	-0.90 °C
Mar:	62 cm	49.6 cm	2.53 cm	-3.90 °C

III. SENSITIVITY ANALYSIS

The influence of the hydrologic, climatic and physiographic parameters of a watershed can be studied and their significance to the water-balance can be evaluated using the mathematical model. This type of study, known as a sensitivity analysis, involves the systematic variation of one or more model parameters while the rest are held constant.

In this chapter, nine model parameters are studied to examine their influence on the water levels and chemistry of a prairie lake. First, the influence of the physical bounds of a lake, including, variations of its surface area (i) and total volume (ii), are examined. Next, the formation of ice (iii) is discussed to determine the functional relationship between the salinity of prairie lakes and parameters of size and initial total dissolved solids content. The significance of groundwater quality (iv) in controlling the salinity of prairie lakes is studied with the model, by systematically varying the groundwater inflow chemistry. Man's influence on natural environment of a watershed is examined to examine hypothetical situations. For example, when land is cleared (v) or drained (vi) for agricultural activities, or the watershed is progressively urbanized (vii). Finally, the influence of climatic variables (precipitation (viii) and potential evaporation (ix)) is discussed with emphasis on

how accurate these data should be in order to adequately model a lake-watershed.

The watershed-lake system used for the sensitivity analysis was designed to present a set of conditions that would be typical for a variety of lakes on the prairies. Five groundwater storage elements (four shallow and one deep) are defined in a watershed with a land area of 300 km^2 and a lake area of approximately 9 km^2. The geological representation of the five groundwater storage elements are:

element 1 = a silt unit with an overlying unsaturated zone
element 2 = a silt unit with no overlying unsaturated zone
element 3 = a till unit with an overlying unsaturated zone
element 4 = a till unit with no overlying unsaturated zone
element 5 = a deep till unit

The schematic representation of the watershed and values of the parameters are illustrated on Figure 9. An example input card deck is listed in Appendix III. All simulations were run over an eight year time period using a time step of one month.

Lake Surface Area, Lake Volume and Ice Formation

Lakes and reservoirs in the Canadian prairies are important water resources. However, problems such as salinity, contamination or declining water levels have significantly impaired the development of these lakes. In Alberta, the provincial government has been active in research to try to reverse this trend by stabilizing the lake levels and improving drainage to and from the lakes (Laycock, 1968, 1971; Gull Lake Task Force, 1970; Reid,

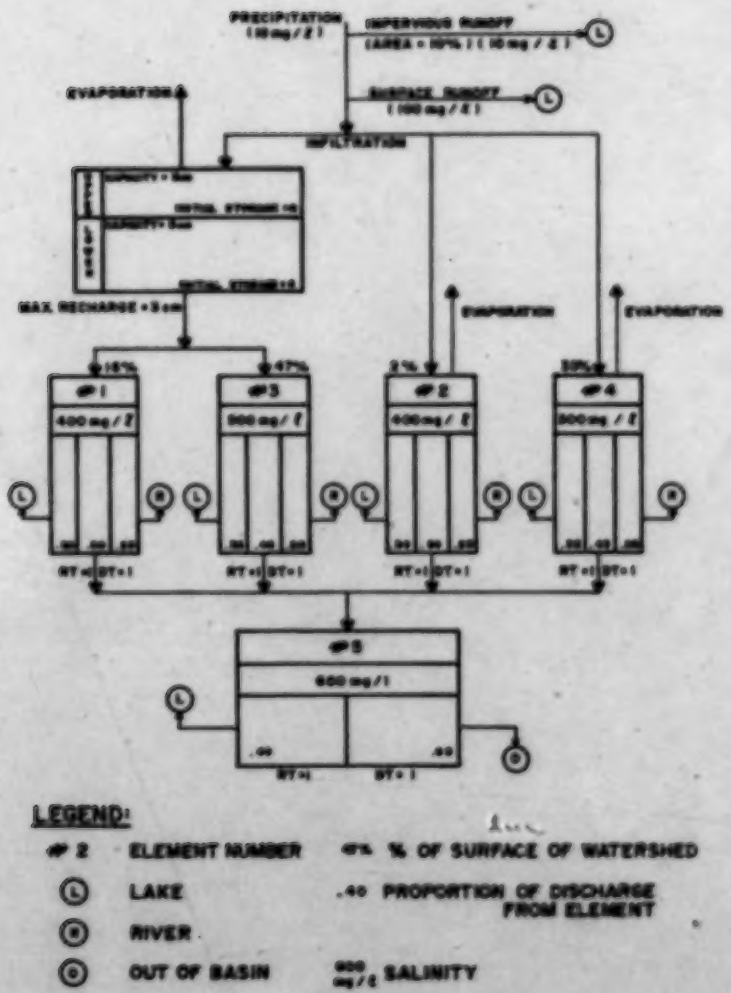


Figure 9. Schematic representation of the watershed model used in the sensitivity analyses.

Crowthers and Partners, 1973; Stanley and Associates, 1974; EPEC Consulting, 1976; Planning Division, 1979)

This section will provide insight into an understanding of how lake or reservoir physiography alterations influence water quality and lake levels. Specifically, the following three questions will be considered:

1. How do water quality and levels vary if the area of the lake is expanded or contracted without a related increase or decrease of the total volume of lake water?
2. What is the impact of increasing or decreasing the volume of water in the lake without a corresponding enlargement or reduction in lake surface area?
3. Does the formation of ice on lakes significantly effect the salinity of lakes during the winter?

Again, it is assumed that no salts are precipitated from the lake. In a real lake, the pattern of salinity increase will be influenced by saturation levels with respect to several minerals. It is also important to note that the saturation level is dependent on the temperature and pH of the lake water. Both of these parameters vary over a year in a prairie lake and hence a complete analysis of lake salinity changes requires that a model incorporate the saturation processes. The lake waters considered in this study are typically undersaturated with respect to many common minerals. Thus, the assumption is valid as a first approximation.

The change in the total dissolved solids content of a

lake with different surface areas is shown in Figure 10. In each case, the total volume of the lake is constant. The most obvious trend is that as the lake area to lake volume ratio increases, the salinity of the lake is increased and the variation in total dissolved solids on an annual basis is enhanced. With a greater lake surface area, potential evaporation and precipitation have a greater influence, causing an overall increase in salinity.

Lakes of a small surface area undergo less annual elevation fluctuations than do those with a larger area, and the overall lake surface elevation is greater (Figure 10). As the surface area of the lake decreases, the area available for evaporation also decreases, and hence less water is lost through evaporation. This relationship is especially evident during the winter when a large proportion of lake water forms ice in a shallow lake.

The infuence of changing lake volumes on salinity were simulated by adding a large volume of water, approximately equal to multiples of the initial lake volume, to the lake. The water is assumed to be added by lowering the lake bottom, thus the lake surface area and lake level fluctuations are constant. The purpose of the analysis is to study the effect of enlarging the volume of a lake or resevoir while its surface area remains the same.

The increase in salinity as the lake volume diminishes (Figure 11) is due to groundwater recharge to the lake. Groundwater inflow to the lake becomes the most significant

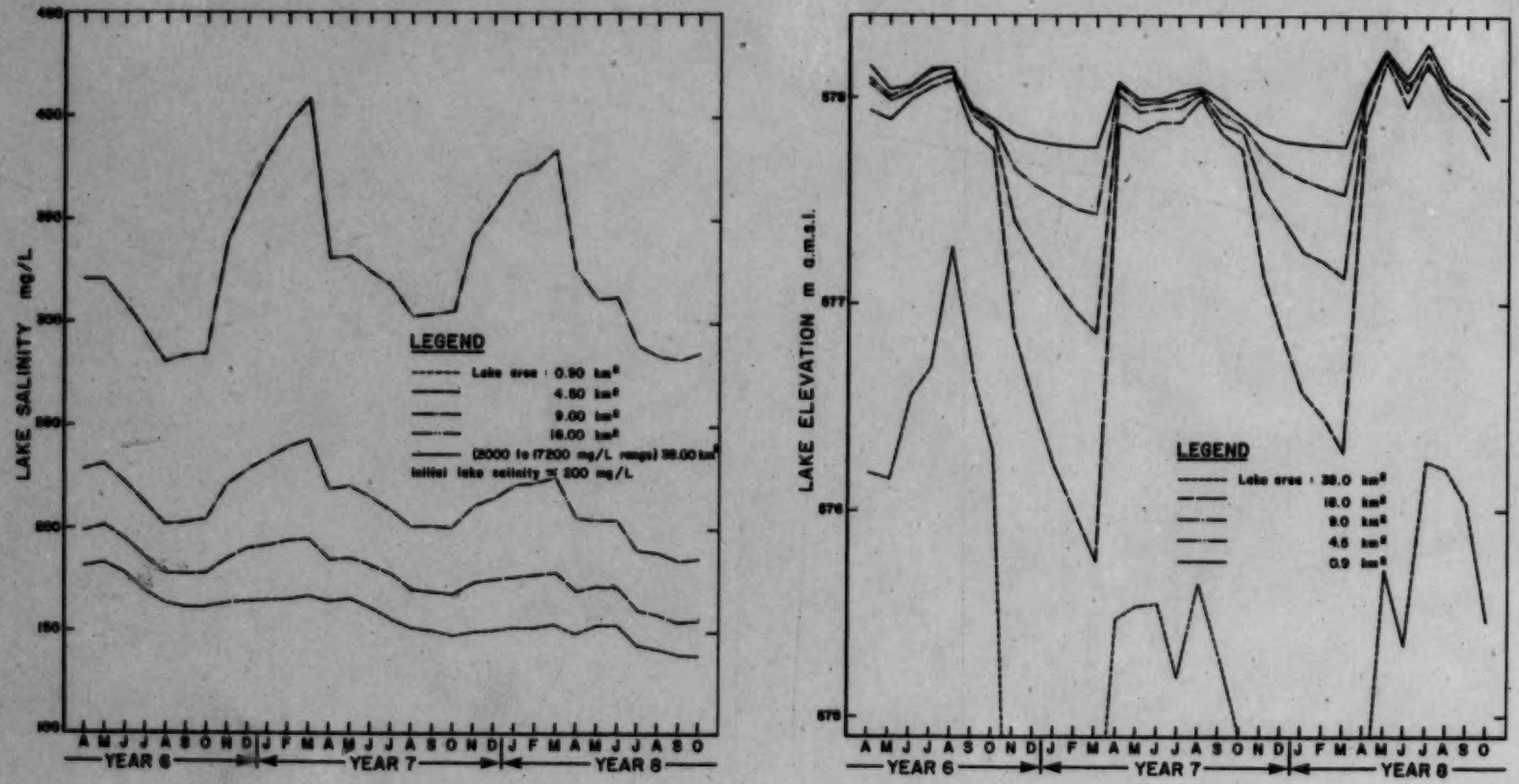

LAKE SALINITY mg/L
LEGEND
Lake area : 0.90 km²
4.50 km²
9.00 km²
18.00 km²
(2000 to 17200 mg/L range) 38.00 km²
Initial lake salinity = 200 mg/L
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8
LAKE ELEVATION m a.m.s.l.
LEGEND
Lake area : 38.0 km²
18.0 km²
9.0 km²
4.5 km²
0.9 km²
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8

Figure 10. Analysis of various lake surface areas in influencing lake levels and salinity.

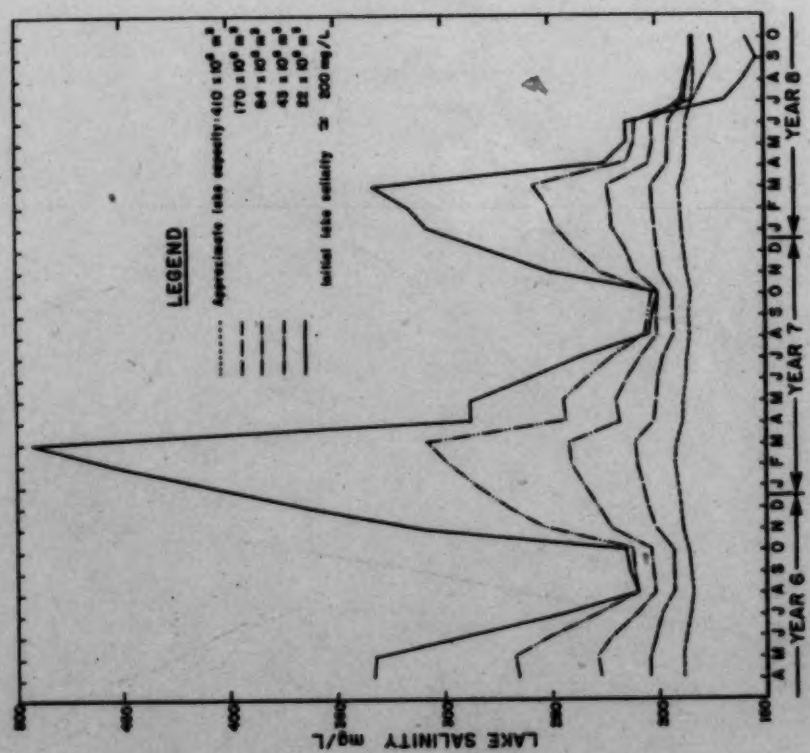

LEGEND
Approximate lake capacity: 410 x 10⁶ m³
170 x 10⁶ m³
84 x 10⁶ m³
43 x 10⁶ m³
22 x 10⁶ m³
Initial lake salinity ≈ 200 mg/L
LAKE SALINITY mg/L
800
600
400
200
100
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8

Figure 11. Analysis of various lake volumes in influencing lake salinity.

process in this watershed, especially in the spring. A large volume of groundwater mixing with a smaller volume of lake water will tend to alter the lake salinity towards that of the groundwater.

The ratio of surface area to total lake volume is very significant in controlling both the salinity of prairie lakes and reservoirs and their surface elevations. Thus if one were physically able to alter the lake by concentrating the same volume of water into a lake with a smaller surface area, or increasing the lake volume without expanding its surface area, the salinity of the lake would decrease and the lake levels would increase. This is tantamount to deeping a lake. In reality, increasing the lake surface elevation will make the surface area larger and the previously discussed controlling factors will influence the lake. The reason for the increase in lake salinity is that as the surface area to lake volume ratio increases, precipiation and potential evaporation exhibit an increasingly greater influence. Concentrating water into a lake with a smaller surface area has a net effect of increasing the land area of the watershed and will cause the same results. These results correspond to Laycock's (1968, 1971) lake stabilization studies, in which he proposed that evaporation losses would decrease if the surface area of the lake available for evaporation were reduced and the depth increased. Hence, the lake level would be higher and the salinity lower. In the same reports, it was stated that by

expanding a watershed, through lake or stream flow diversion across a watershed boundary, higher lake levels would result.

Ice formation is also very important in influencing the salinity of lakes during the winter, especially if the lake or reservoir is saline, or if the proportion of lake water that is taken up during ice formation is large relative to total storage of lake water. A greater proportion of lake water will be frozen in shallower lakes than deep lakes (Figure 10 and 11), and hence, all dissolved lake salts will be concentrated in a smaller volume of water.

Groundwater Chemistry

There are two reasons for conducting a sensitivity analysis using groundwater chemistry as a variable. Firstly, to provide insight into how lake salinity may be controlled by groundwater chemistry. Secondly, an analysis can help determine how accurately this component should be defined by field measurements in order to adequately model the watershed. Typically, the quality of groundwater is quite variable, especially in the shallow groundwater regime, and is hard to know entirely.

The salinities of the various groundwater storage elements used in the six trials are listed on Table 3. These salinities are typical of observed groundwater conditions in the prairies.

Table 3.

CHEMISTRY OF GROUNDWATER STORAGE ELEMENTS

(all salinities in mg/L)

trial #1		trial #2		trial #3	
element	salinity	element	salinity	element	salinity
1	200	1	400	1	400
2	200	2	400	2	800
3	250	3	500	3	500
4	250	4	500	4	500
5	300	5	600	5	600

trial #4		trial #5		trial #6	
element	salinity	element	salinity	element	salinity
1	400	1	500	1	800
2	400	2	500	2	800
3	1000	3	625	3	1000
4	500	4	625	4	1000
5	600	5	750	5	1200

Results obtained with this hypothetical lake-watershed system (Figure 12), show that the lake is not particularly sensitive to even large changes in the groundwater chemistry of part of the basin, but that changes in the groundwater chemistry of the entire basin may significantly alter the salinity of the lake. For example, a 100% increase in the salinity of a small groundwater storage element, such as in run #3, or a large element, run #4, resulted in only a minimal change to the lake. Run #6 was conducted with the groundwater salinity 100% higher in all storage elements than the initial run (#2) and the resultant lake salinity is approximately 75% higher. An overall increase of 25% of the groundwater salinity (run #5) raised the salinity of the lake by approximately 20%. The implications of this analysis

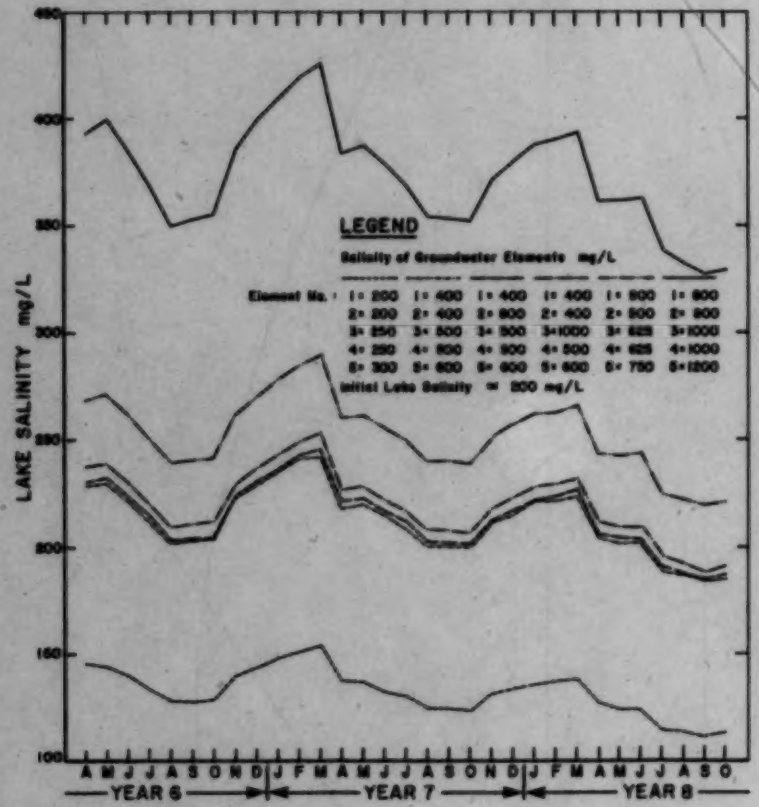


Figure 12. Analysis of various groundwater salinities in influencing lake salinity.

would be that in a prairie watershed system, similar to that modelled here, influences which cause an increase in the groundwater salinity over a small part of the watershed would not significantly alter the chemistry of the lake.

Land Use

Man has greatly influenced all aspects of the environment. Urban development, agriculture, forestry and land reclamation can, within a time-span of a few years or even a few months, affect all systems. This section will demonstrate the possible impact of two common activities within a watershed; (i) increasing the proportion of the watershed that is covered by an unsaturated zone, and (ii) increasing the area of the watershed that is occupied by an impervious area. Laycock (1971, 1973) suggested that a change in the land from forest cover to cropland or pasture would produce more surface runoff and less groundwater flow to a lake. Thus lake levels would increase and the quality of the lake would be enhanced, assuming that erosion not increase.

The effect of changing the land cover for lake-watershed management programs is worth investigating via sensitivity analyses. Unfortunately, this requires data on vegetation types, rooting depths and moisture use by various plant species, which is beyond the scope of this model. However, the modelling of land use changes can be attempted by the general grouping of land covers into

forest, wet-lands, cropland and pasture. These various categories affect the areal extent of the unsaturated zone and its moisture capacity. Therefore, two analyses shall be conducted by: (i) simulating the draining of wet-lands by increasing the portion of the watershed that is occupied by an unsaturated zone, and, (ii) studying the change from forest cover to pasture or cropland by reducing the moisture capacity of the unsaturated zone (Laycock, 1967, 1968, 1971; Gray et al., 1970).

Decreasing the unsaturated zone moisture capacity in the model resulted in greater recharge to the groundwater storage elements, and hence, greater groundwater discharge to the lake because less precipitation was retained in the unsaturated zone. Surface runoff increases because of the tendency for percolation to exceed the maximum groundwater infiltration rate during periods of intense precipitation. Of these two factors, groundwater discharge is the more prominent and acts to raise the lake levels and increase the salinity (Figure 13). A noticeable change in lake levels did not result because water had not significantly exceeded the unsaturated zone moisture capacity.

The increased surface runoff and increased lake levels, corresponding to a decreasing unsaturated zone moisture capacity, is in agreement with Laycock's (1971, 1973) findings. However, the increased groundwater discharge and greater lake salinity are opposite to his findings. The reason for increased groundwater discharge found in this

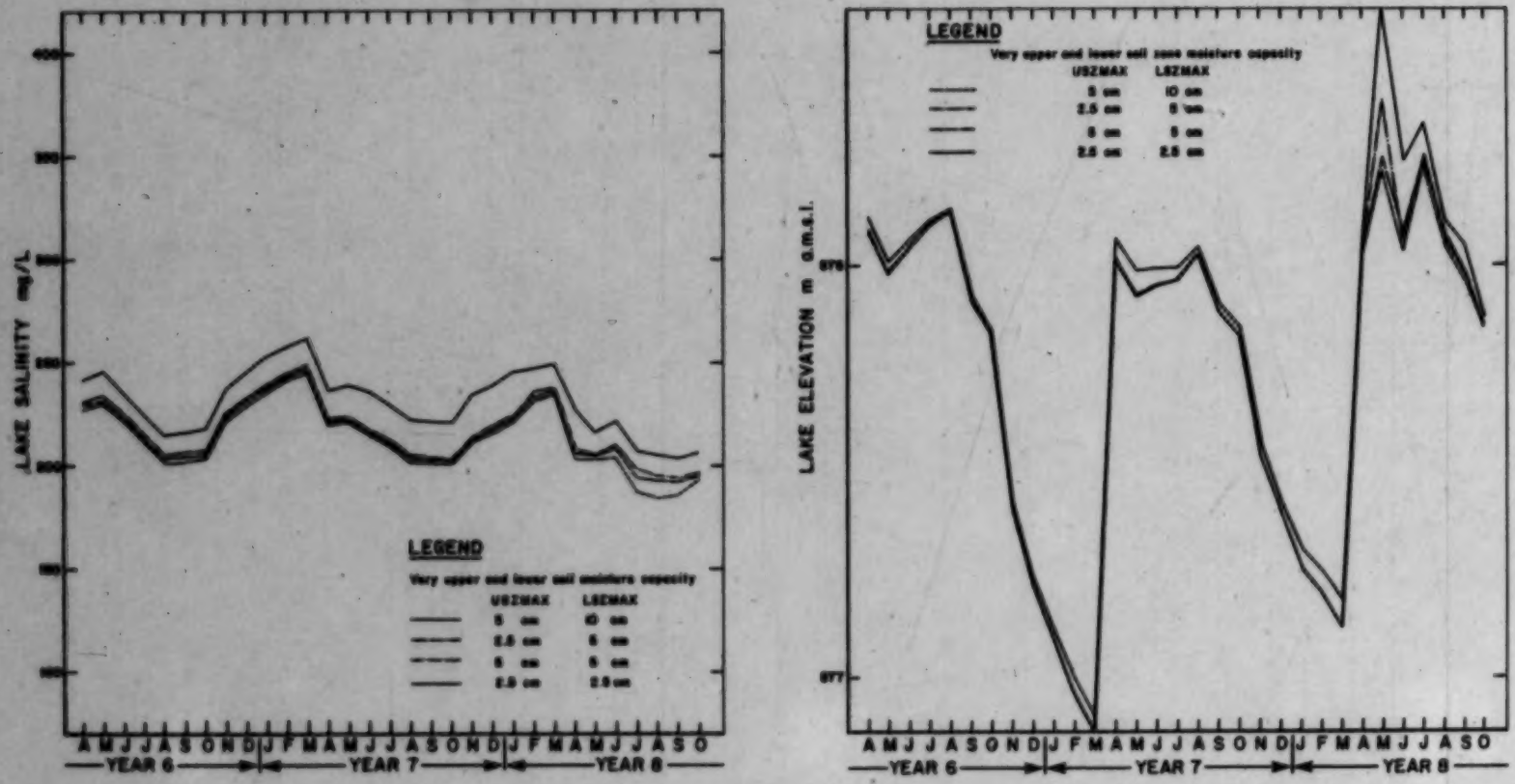


Figure 13. Analysis of various unsaturated zone moisture capacities in influencing lake levels and salinity.

watershed is that more water is able to recharge the groundwater zone; hence, more is discharged to the lake as groundwater, raising the salinity of the lake. Should a decrease in the unsaturated zone moisture capacity be accompanied by a larger groundwater recharge rate, the groundwater discharge and lake salinity would increase as suggested by Laycock (1971, 1973).

The next part of this sensitivity analysis will examine the influence that increasing the portion of the basin which is occupied by an unsaturated zone has on lake levels and salinity. The analagous real situation would be the draining of wet-lands, which are lands occupied by sloughs, swamps, muskeg or high watertables. It should be noted that when a wet-area is drained, the water will be diverted directly to a lake or a river. The increased surface runoff will produce higher lake levels and increase water flow through the lake, resulting in improved lake water quality (Laycock, 1968, 1971). However, in this study only the unsaturated zone area is enlarged; the drainage from former wet-lands does not increase. It is assumed that the land has been drained for a sufficient length of time for the watershed to reach an equilibrium with the increased area underlain by an unsaturated zone.

Increasing the proportion of the watershed that is covered by an unsaturated zone reduces the salinity of the lake and lowers the surface elevations (Figure 14). It is proposed that the total recharge to the lake is decreased as

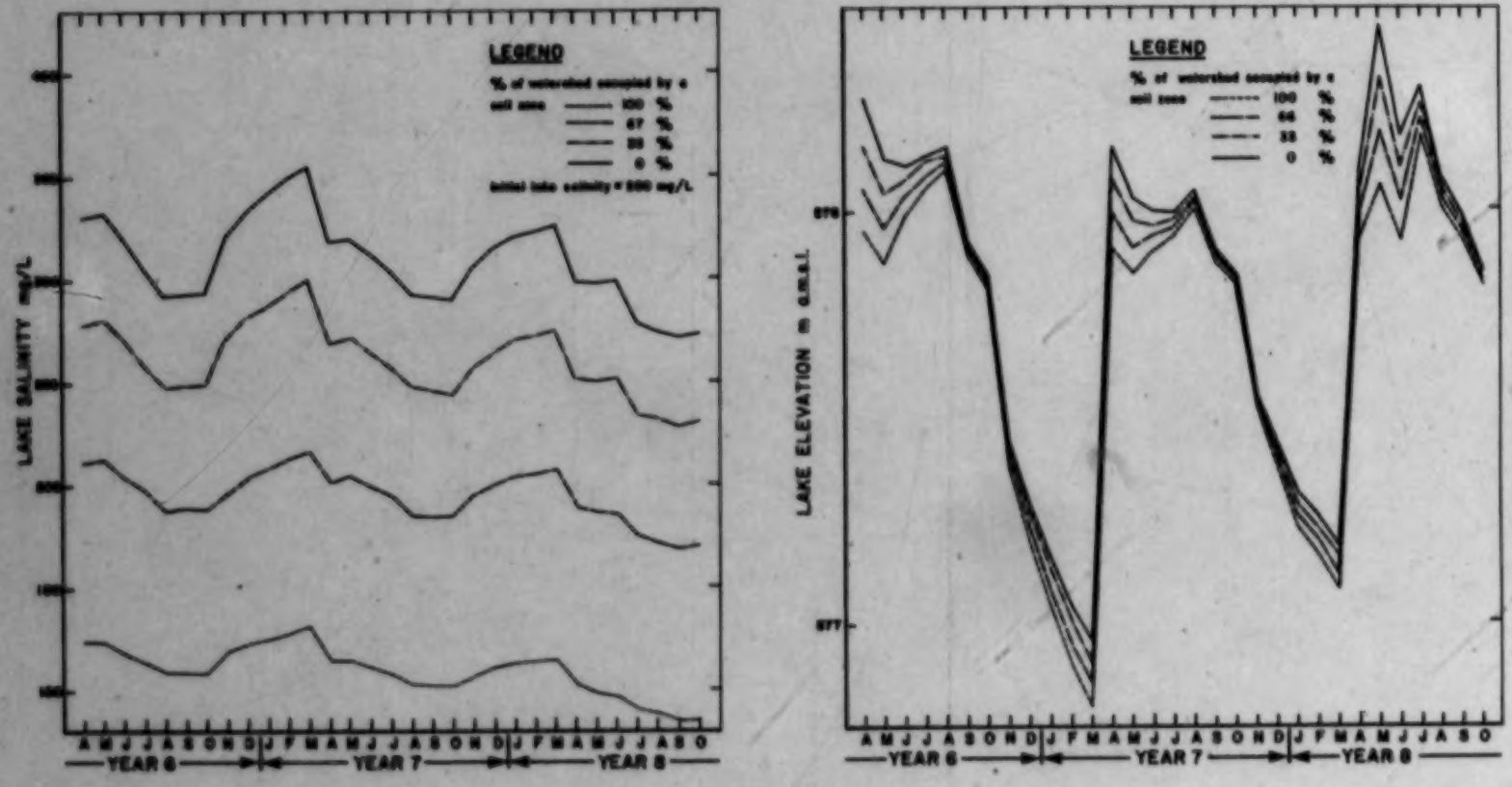


Figure 14. Analysis of various areal extents of an unsaturated zone in influencing lake levels and salinity.

the extent of the unsaturated zone is enlarged because less water (especially groundwater) is discharging to the lake. Lake water chemistry responds in the expected manner with a decrease in the total dissolved solids. In this example, groundwater is the major contributor of dissolved solids to the lake and a decrease of groundwater inflow to the lake will significantly reduce lake salinity. Also, fluctuations of the lake water chemistry decrease as the unsaturated zone area increases (Figure 14). The greater variability in chemistry among simulations during the winter is due to the effect that the formation of ice has on different lake salinities. Thus, the net effect of draining wet-areas, as indicated by this study (decreased lake levels and salinity), would appear to be due to reduced groundwater recharge. It can be concluded that as the area of the watershed that is covered by an unsaturated zone increases, less water will reach the groundwater system or discharge as surface runoff because the water requirements of the unsaturated zone must first be fulfilled before any groundwater recharge occurs. Another implication of this analysis is that the lake is quite sensitive to the proportion of the basin that is occupied by an unsaturated zone and this parameter should therefore be defined carefully. In this watershed, a 10% increase in the unsaturated zone area resulted in an approximate 15 mg/L drop in lake salinity. Similarly, lake levels are much higher in the spring if the unsaturated zone is not very

large, due to surface runoff and groundwater discharge.

The main effects of urbanization on a watershed are primarily an increase in the amount of impervious area by the construction of roads and buildings. This causes a decrease in the time required for runoff and contaminants to reach a lake or river through storm sewers and lined drainage ditches (Crawford and Linsley, 1966). Water falling on these impervious areas will be directly discharged to a lake or a river. As previously stated, isolated impervious areas are not considered to be part of the impervious area parameter because surface runoff from here must flow over pervious land before reaching surface water bodies.

The fact that increasing the portion of the watershed that is impervious has on the lake stage and lake salinity is illustrated on Figures 15. As greater porportions of the watershed are covered by impervious areas, more precipitation is routed directly to the lake, with a resulting decrease in lake salinity. Even a small increase of the impervious area, involving as little as 1% of the watershed in this example, caused a decrease of the lake salinity by 10 mg/L. The reason for this is that surface runoff becomes increasingly important relative to groundwater. The lake level is higher and the fluctuations are greater when the impervious area increases.

The results of this analysis correspond to Crawford and Linsley's (1966) experience with several watersheds, suggesting that the influence of impervious areas found in

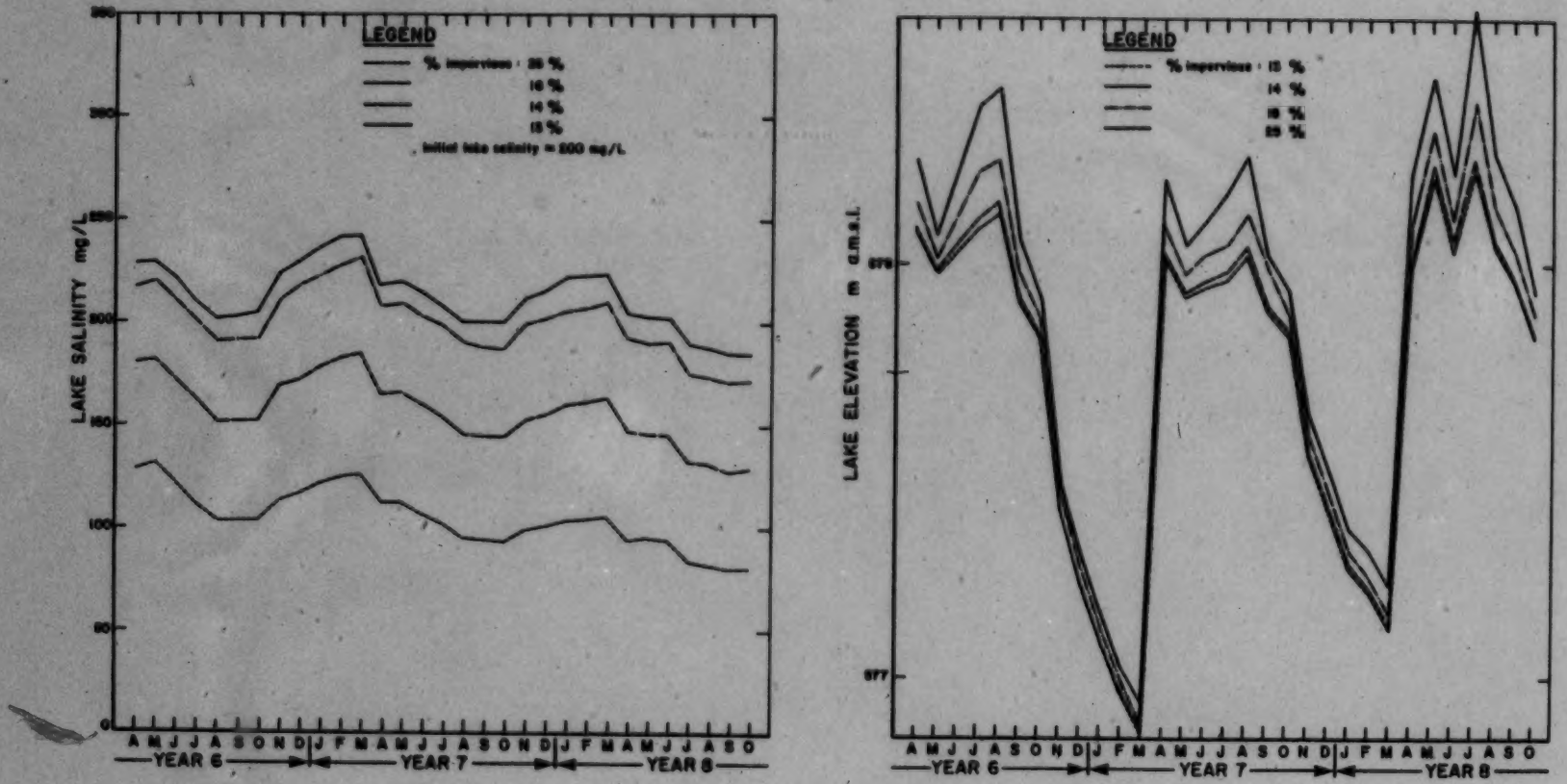

LEGEND
% impervious : 18 %
16 %
14 %
12 %
initial lake salinity = 500 mg/L
LAKE SALINITY mg/L
LAKE ELEVATION m a.m.s.l.
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8

Figure 15. Analysis of various impervious areas in influencing lake levels and salinity.

this study is common. Precipitation is no longer routed to the lake via groundwater storage elements, but becomes surface runoff. Thus the flow length has been reduced and the time delay for water to reach the lake decreased, enabling the surface runoff from a given storm to reach the lake at faster rate and in greater amounts.

The sensitivity analysis indicates that the impervious cover is an important watershed parameter controlling lake salinity. Accurate values should be obtained by either field study or a detailed calibration procedure.

Precipitation and Potential Evaporation

For many watersheds on the prairies, there are often no meterological recording stations located in the specific areas being studied. Because data must be interpolated or extrapolated from the nearest stations, they are accompanied by uncertainties. Parameters that are not always measurable, such as potential evaporation from lakes, reservoirs, forested land and agricultural areas, can be estimated by a number of formulae and methods. The accuracy of these estimates is often doubtful because of the many influencing factors. This part of the sensivity analysis will examine the level of accuracy required for precipitation and potential evaporation data in order to adequately model lake level and salinity fluctuations.

The effect on lake levels of over-estimating or under-estimating precipitation and potential evaporation by

up to 25% in various sizes of watersheds, are shown on Figures 16b and d, 17b and d, 18b and d. As expected, as potential evaporation increases, the elevation of the lake surface declines and increasing precipitation will cause the lake level to rise.

The changes of the lake level are also dependent on the size of the watershed. When precipitation varies by as much as 25% on the large watersheds used in this example (greater than 200 km^2), the level may only change by a small amount; less than .25 m, as shown on Figures 17b and 18b. But when the small (50 km^2), watershed was tested. a 25% variation resulted in a lake level change of almost 2 m (Figure 16b). In cases where potential evaporation was varied, a similar trend could be observed. A deviation of approximately .05m occurs in the large watersheds (Figures 17d and 18d), but the smaller watershed shows that a 25% change resulted in a lake level variation of almost 1 m (Figure 16d). It should also be noted that the deviation from the normal lake level in a small watershed is greater when precipitation or potential evaporation are under-estimated, than if they are over-estimated.

The effect on lake chemistry of changing these parameters is more difficult to explain. Another parameter, watershed size plays an important role in determining lake salinity. Figures 16a and 16c show the result of increasing or decreasing precipitation and potential evaporation by up to 25% in the small watershed used in the previous analysis.

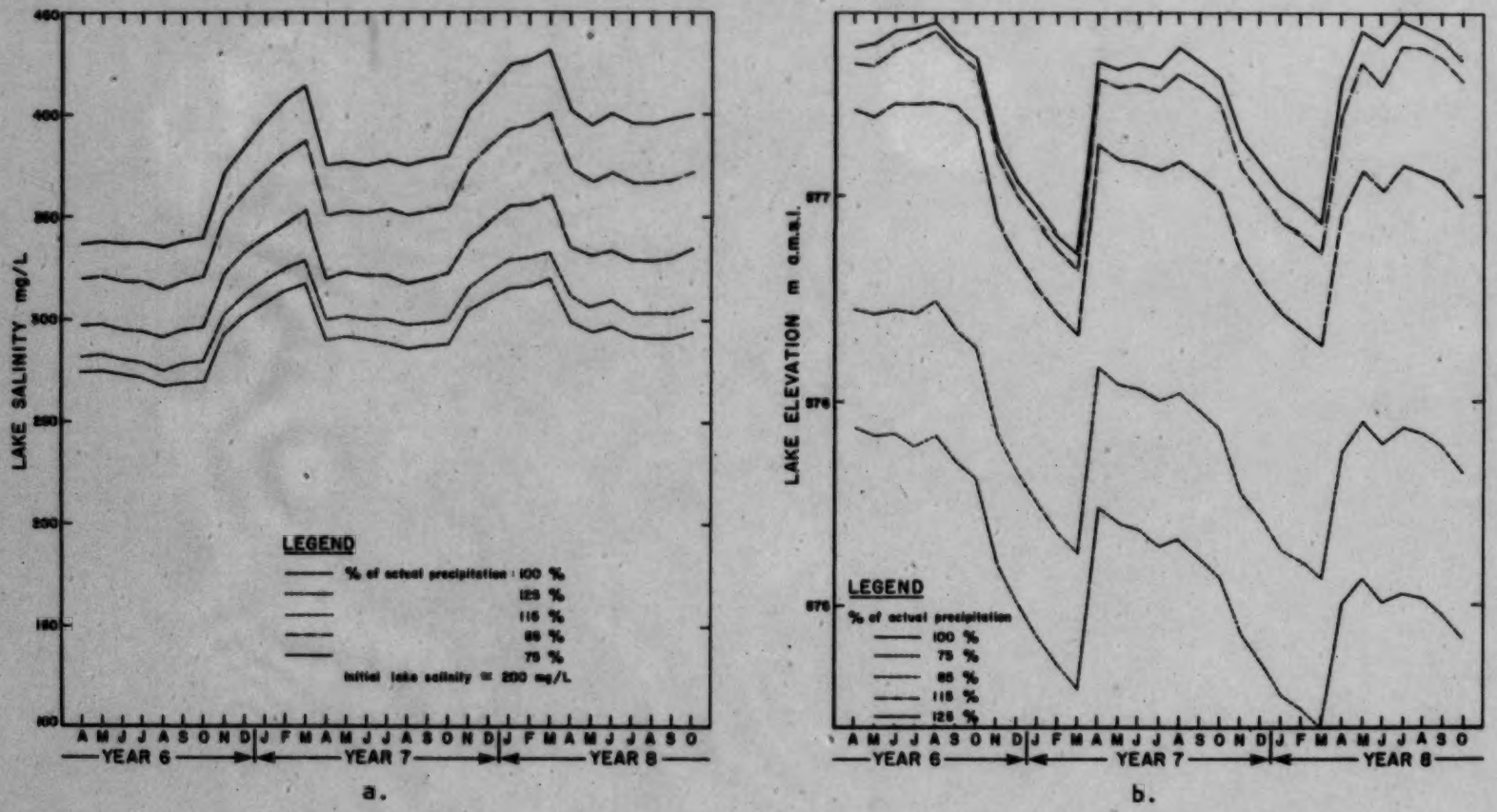
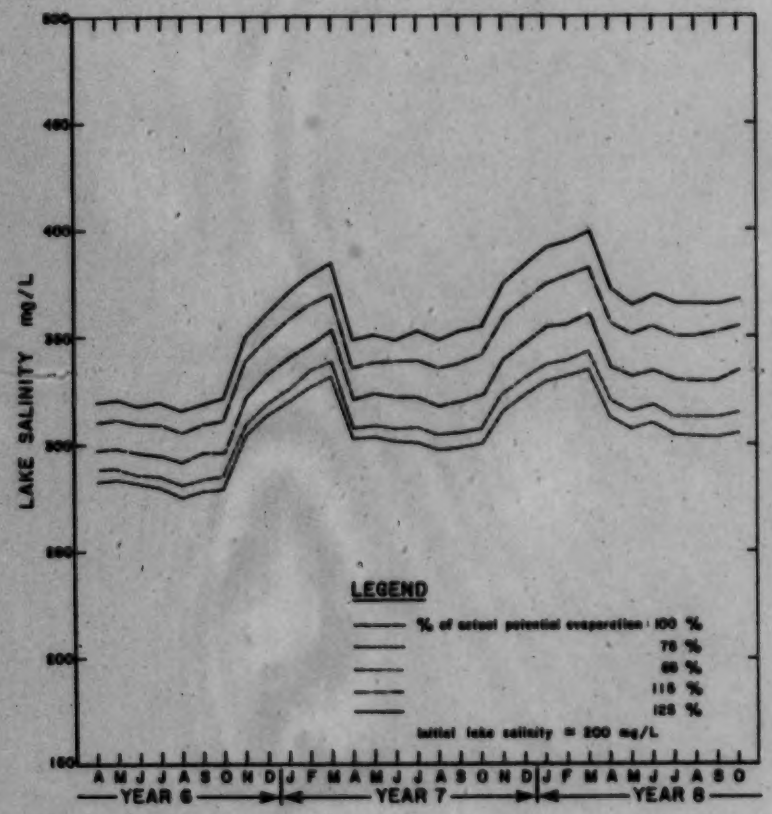
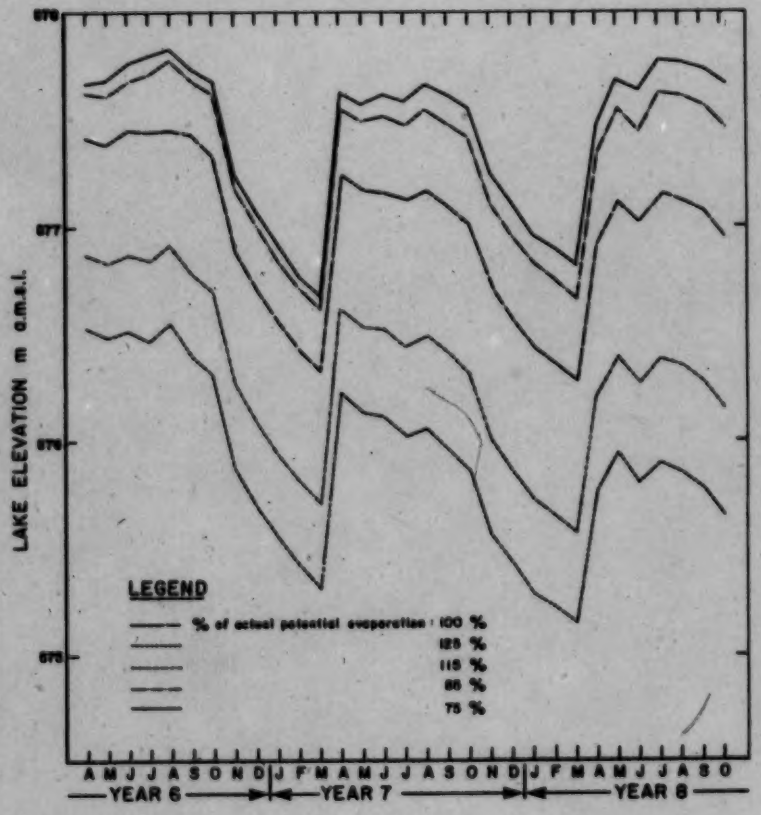

LAKE SALINITY mg/L
LEGEND
% of actual precipitation : 100 %
125 %
115 %
85 %
75 %
Initial lake salinity = 200 mg/L
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8
a.
LAKE ELEVATION m a.m.s.l.
LEGEND
% of actual precipitation
100 %
75 %
85 %
115 %
125 %
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8
b.

Figure 16. Analysis of varying precipitation and potential evaporation, separately, in influencing lake levels and salinity in a 50 km^2 watershed.


LAKE SALINITY mg/L
LEGEND
% of actual potential evaporation : 100 %
75 %
85 %
115 %
125 %
Initial lake salinity = 300 mg/L
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8

c.


LAKE ELEVATION m a.m.s.l.
LEGEND
% of actual potential evaporation : 100 %
125 %
115 %
85 %
75 %
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8

d.

Figure 16. Analysis of varying precipitation and potential evaporation, separately, in influencing lake levels and salinity in a 50 km^2 watershed.

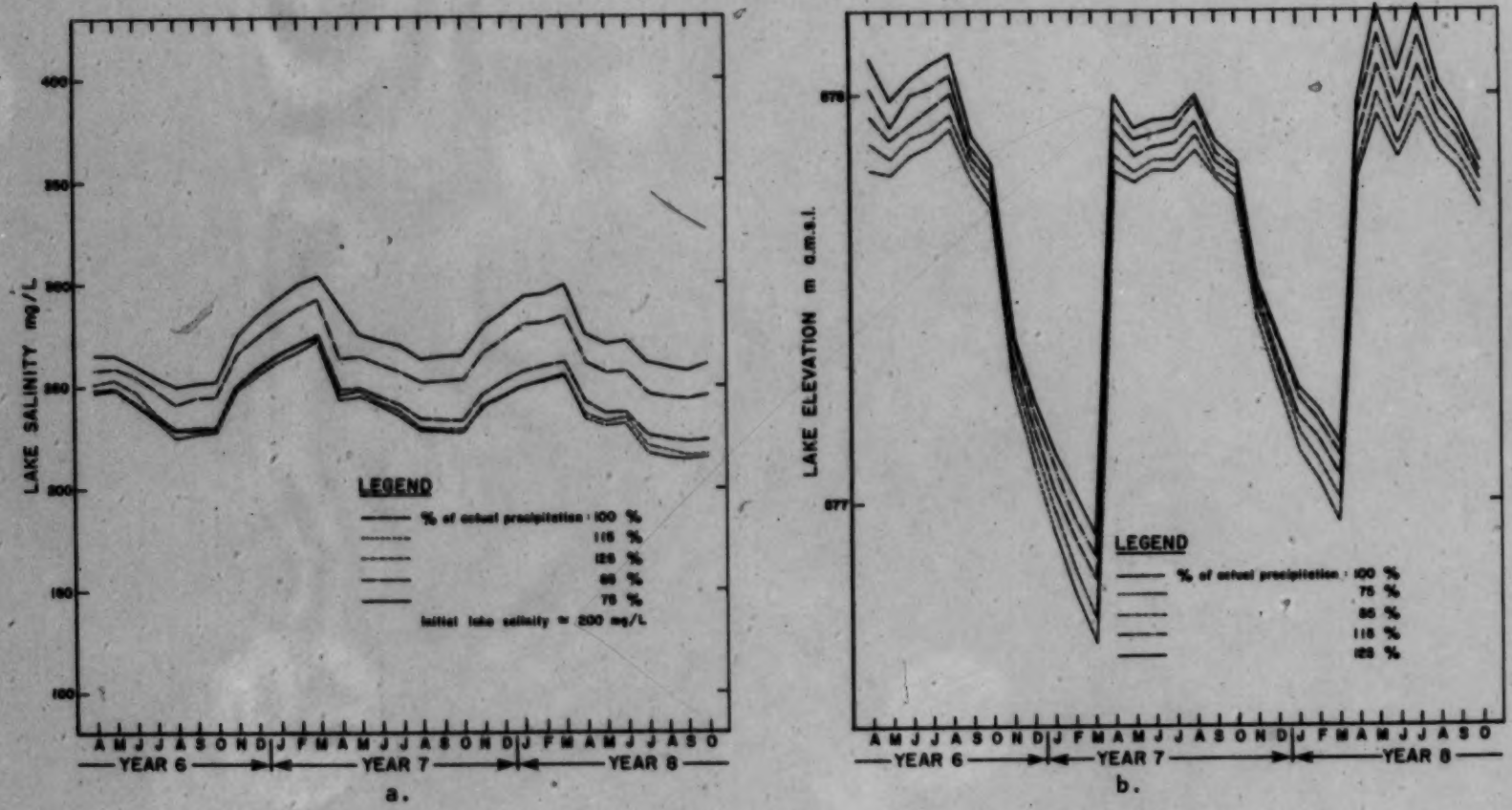
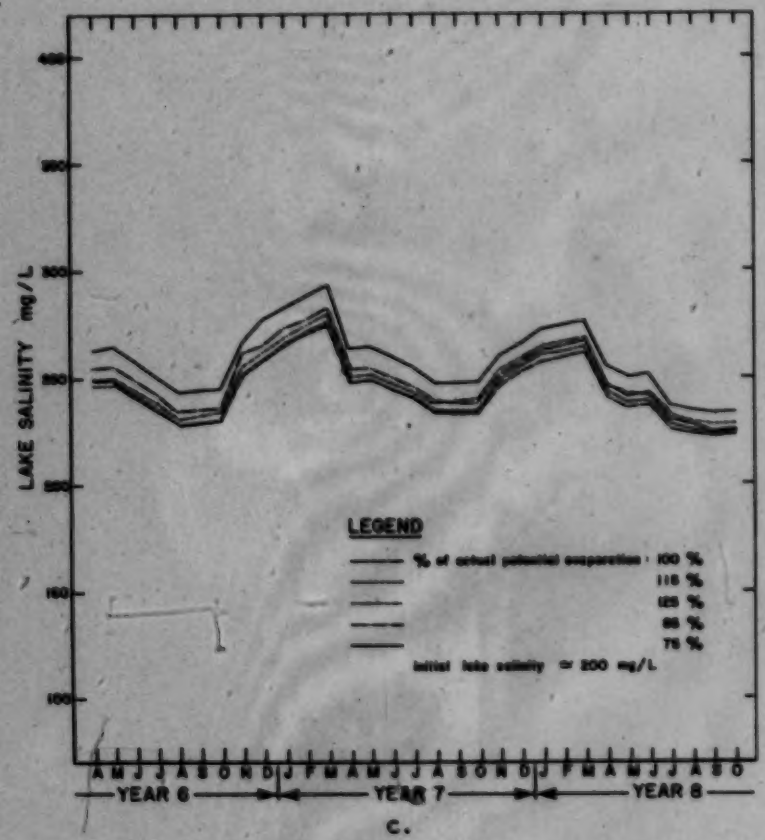
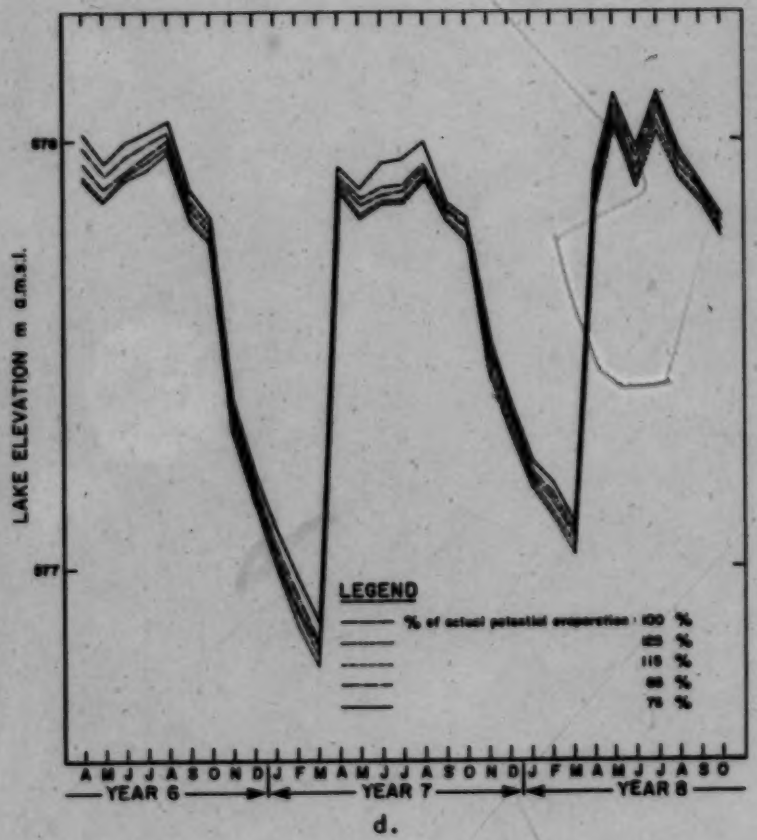

LAKE SALINITY mg/L
LEGEND
% of actual precipitation : 100 %
115 %
125 %
85 %
75 %
Initial lake salinity = 200 mg/L
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8
a.
LAKE ELEVATION m a.m.s.l.
LEGEND
% of actual precipitation : 100 %
75 %
85 %
115 %
125 %
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8
b.

Figure 17. Analysis of varying precipitation and potential evaporation, separately, in influencing lake levels and salinity in a 200 km^2 watershed.


LAKE SALINITY mg/L
LEGEND
% of actual potential evaporation
100 %
115 %
85 %
75 %
Initial lake salinity = 200 mg/L
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8

c.


LAKE ELEVATION m a.m.s.l.
LEGEND
% of actual potential evaporation
100 %
85 %
115 %
75 %
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8

d.

Figure 17. Analysis of varying precipitation and potential evaporation, separately, in influencing lake levels and salinity in a 200 km^2 watershed.

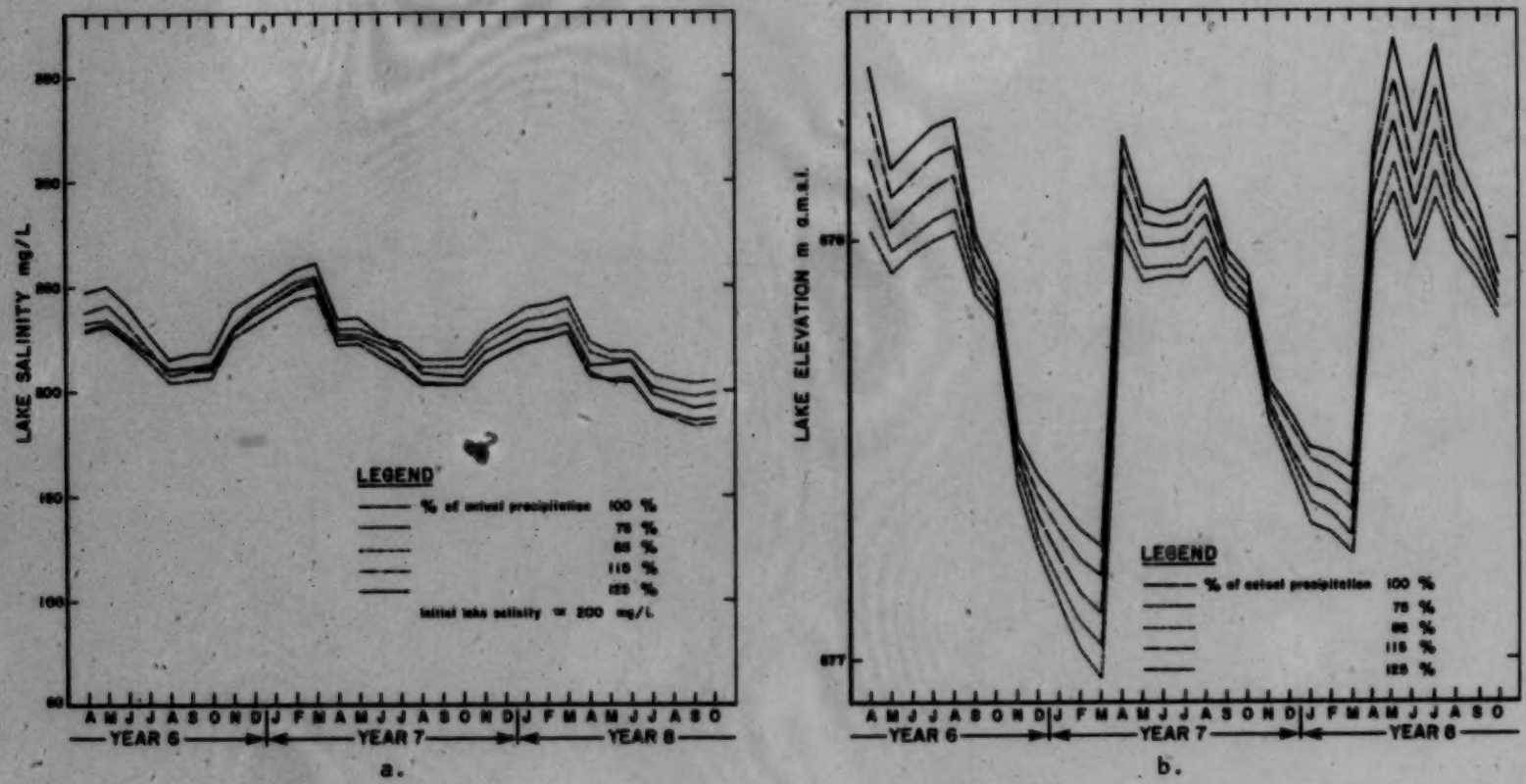
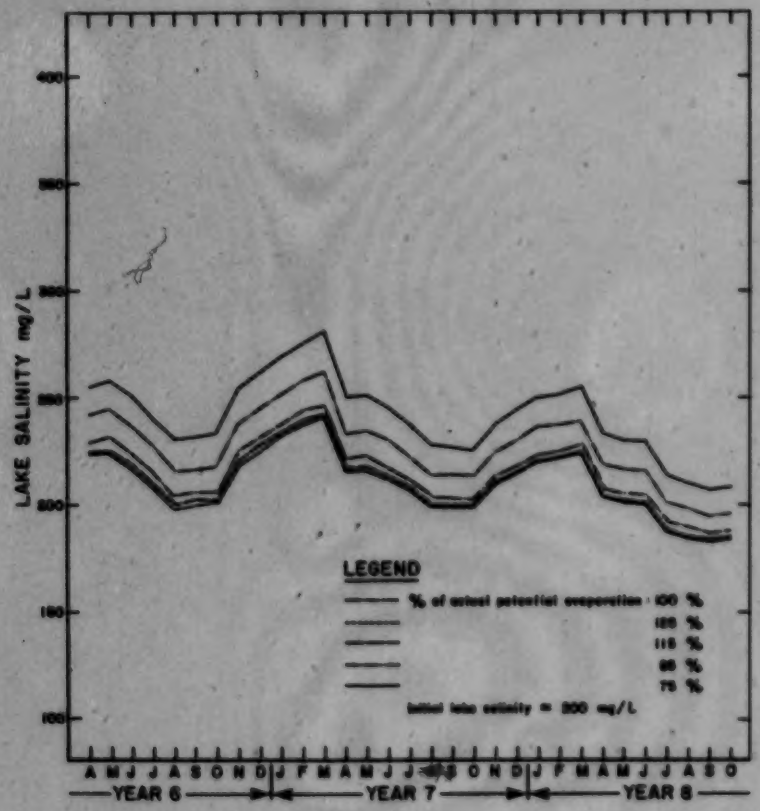

LAKE SALINITY mg/L
LEGEND
% of actual precipitation 100 %
75 %
85 %
115 %
125 %
Initial lake salinity = 200 mg/L
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8
a.
LAKE ELEVATION m a.m.s.l.
LEGEND
% of actual precipitation 100 %
75 %
85 %
115 %
125 %
A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
YEAR 6
YEAR 7
YEAR 8
b.

Figure 18. Analysis of varying precipitation and potential evaporation, separately, in influencing lake levels and salinity in a 300 km^2 watershed.



c.

d.

Figure 18. Analysis of varying precipitation and potential evaporation, separately, in influencing lake levels and salinity in a 300 km^2 watershed.

It is not surprising to observe that as precipitation increases, lake salinity is lowered, and that as potential evaporation increases, lake salinity is raised, indicating that precipitation and potential evaporation from the lake surface become the most important processes controlling the chemistry of the lake. However, as the area of the test watershed increases relative to the lake area, groundwater discharge becomes a more significant factor controlling lake chemistry. Because the groundwater of the test watersheds have a relatively high salinity, a greater contribution of groundwater to the lake, (relative to other sources of water such as surface runoff and precipitation falling directly on the lake), will cause the salinity of the lake to approach that of the groundwater. Increasing potential evaporation or decreasing precipitation over a large watershed results in a lower lake salinity (Figure 18a and 18c), because there is less groundwater being discharged to the lake. A similar effect in the large watershed can be noted when precipitation is increased by 25% and potential evaporation is reduced by 25%; groundwater recharge is increased and therefore, groundwater discharge is also greater, contributing more total dissolved solids to the lake and increasing its salinity.

In the previous sensitivity analyses, either precipitation or potential evaporation were varied. However, the more realistic situation is for them to vary together. If precipitation increases, there are fewer days in which

evaporation may occur. Thus potential evaporation would decrease and vice versa. Figure 19 illustrates the results for model trials for a 15% increase and decrease in precipitation with a respective 15% decrease and increase in potential evaporation. Here, the lake surface varies up to .15m and the lake water quality varies by only 25 mg/L.

After conducting this sensitivity analysis, the following conclusions can be stated for these and similar watersheds:

1. An error in estimating precipitation and potential evaporation may not significantly alter the calculated lake salinity and lake surface elevations of a large lake-watershed, but over-estimating or under-estimating precipitation and potential evaporation may cause significant deviations in a small watershed (less than 100 km^2). In particular, under-estimating precipitation or over-estimating potential evaporations causes a much larger lake level change than under- and over-estimating potential evaporation and precipitation, respectively. Therefore, in watersheds similar to those tested here, it may be concluded firstly, that more accuracy is required for a small lake-watersheds than for a large one, and, secondly, that if the actual values for a small watershed are unknown, better lake level and salinity simulations may be obtained when potential evaporation is under-estimated and precipitation is over-estimated.

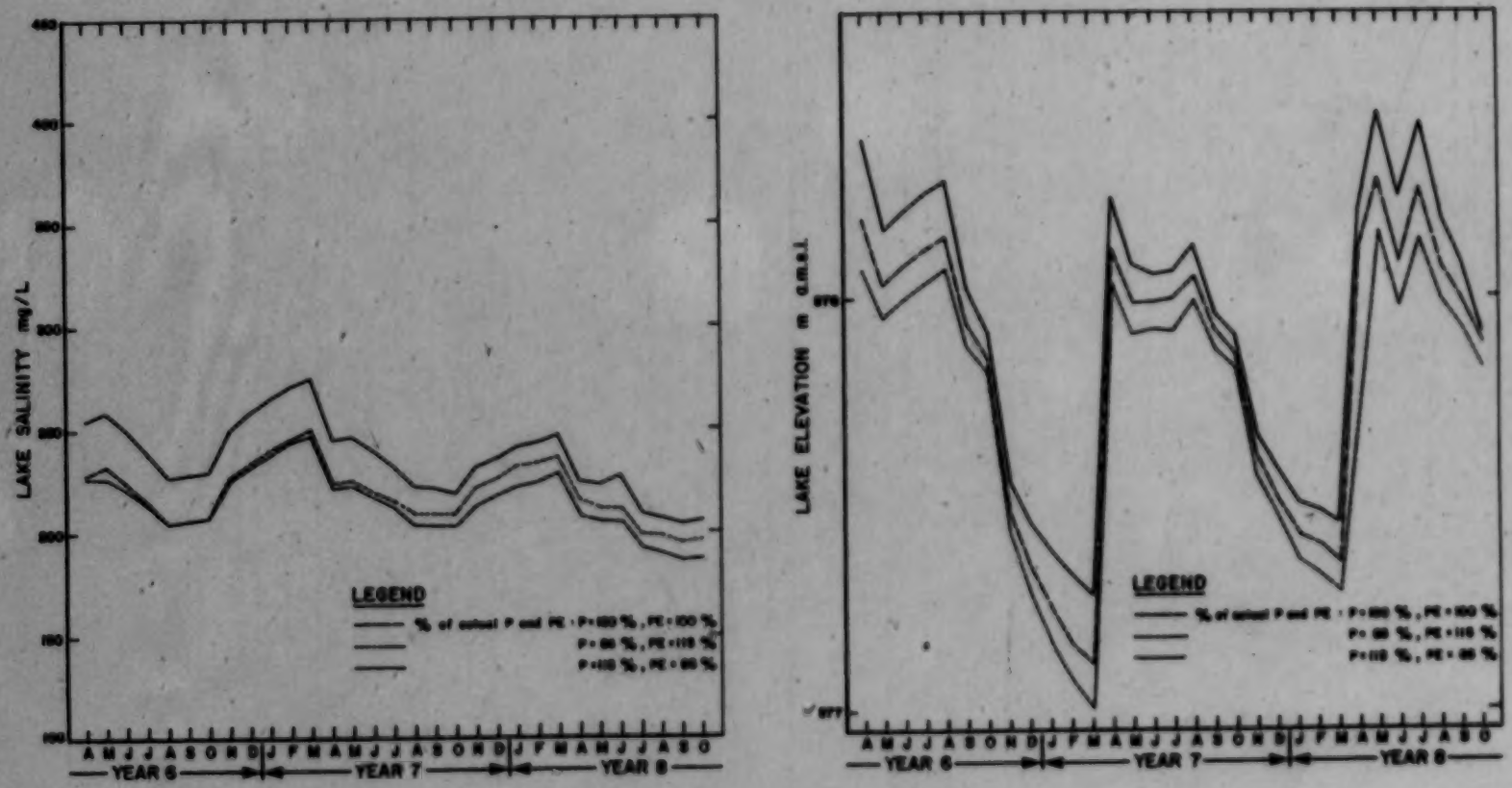


Figure 19. Analysis of varying precipitation and potential evaporation, together, in influencing lake levels and salinity.

2. The results of the simulations can be generalizable in saying that precipitation to, and potential evaporation from a lake in a small watershed plays a more prominent role in controlling lake salinity than does groundwater discharge. This conclusion assumes that the lake is the major groundwater discharge point for the watershed and that as the area of the watershed varied, in these tests, the area of the lake remained essentially constant. It follows that in a larger watershed where groundwater is a major contributor to the lake, groundwater discharge is the main process controlling lake salinity. In this case, decreasing potential evaporation or increasing precipitation will increase groundwater recharge, hence, increased groundwater discharge to the lake. This groundwater inflow will increase the salinity of the lake.

IV. APPLICATION TO THE BAPTISTE LAKE WATERSHED

This chapter will demonstrate a practical application of the model to the Baptiste Lake watershed. Important features of the basin such as physiography, geology, hydrogeology and hydrology will be reviewed in the following sections. The purpose of this description is to give the reader a better insight into the choice of parameters for the simulation. Following this discussion is an analysis of the simulation. Finally, a few specific applications of the model to the Baptiste Lake watershed are presented.

General Discription of the Watershed

Baptiste Lake is located in the Eastern Alberta Plains physiographic region, approximately 130 km north of Edmonton, Alberta (54° 45' N, 113° 33' W). The watershed (Figure 20) covers an area of approximately 308.9 km², of which 58% is forest, 25% is standing water consisting of Baptiste lake, swamps and rivers, 16% is agricultural and less than 1% is urban; mainly cottage development along the shore of the lake. The land to the north and east of the lake is primarily farm land, while that to the west and south is primarily swamp and forest.

Land elevations range from 578 m above mean sea level at the surface of Baptiste Lake, to over 690 m a.m.s.l. west of the lake. The area of the lake is approximately 9.2 km²

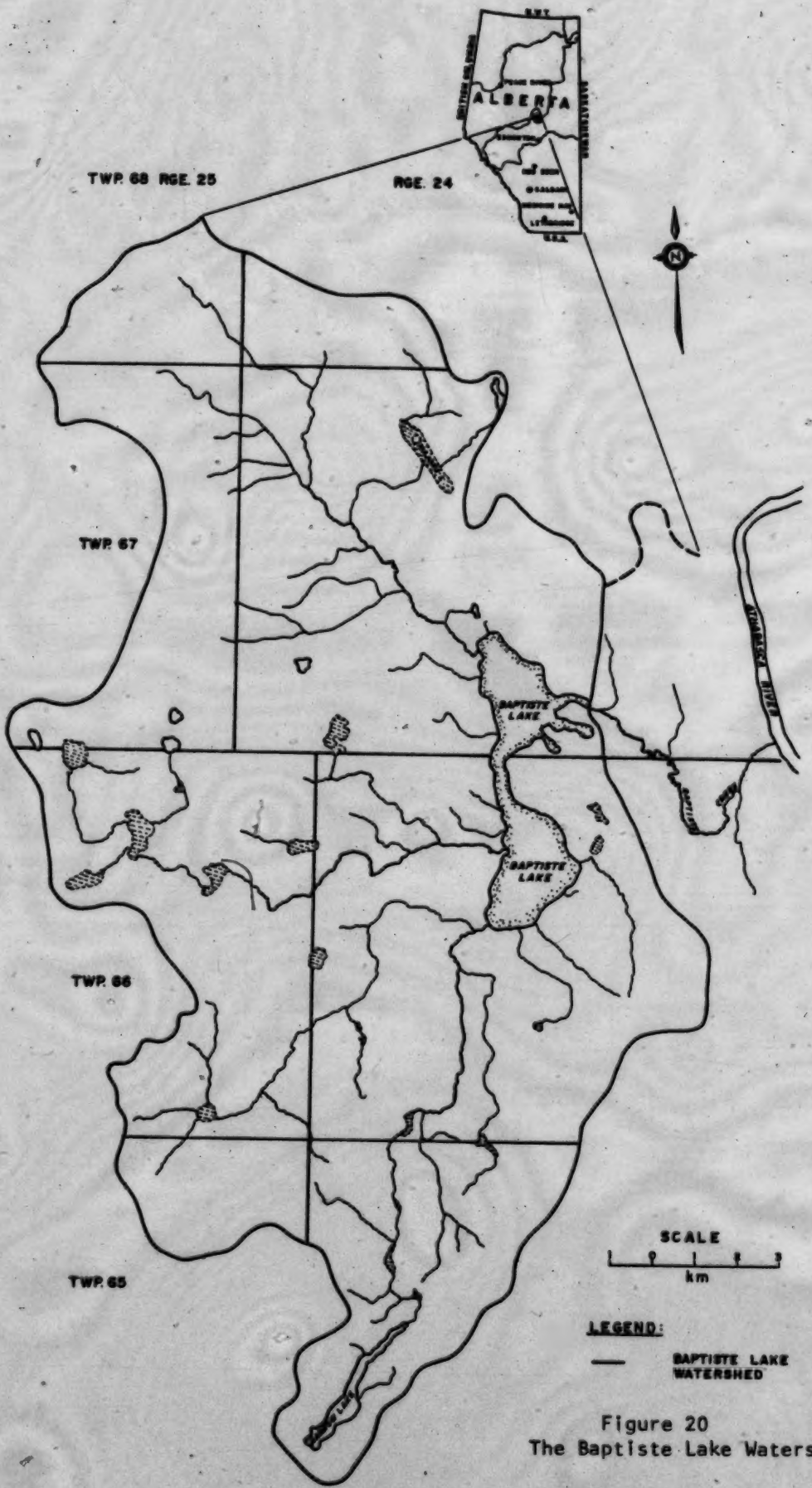


Figure 20
The Baptiste Lake Watershed

with a maximum depth of 27.5 m and a volume of 8.5 * 10^7 m^3 (± 10%) at an elevation of 578.35 m a.m.s.l. Twelve tributary streams flow into the lake. One outlet, Baptiste Creek, drains the lake and flows east to the Athabasca River.

Field Work

Two programs involving deep test-hole drilling were undertaken to investigate the regional geology and hydrogeology and to determine whether the buried preglacial bedrock valley reported by Borneuf (1973) is present beneath Baptiste Lake. Thirteen test-holes were drilled with a rotary rig through the glacial drift and into the upper few meters of bedrock (Figure 21). All boreholes were logged geophysically. A summary of the results of this program is presented in Appendix VIII. Readers interested in a more complete description of the programs can refer to Crowe (1978).

Three observation wells were completed in the sand and gravel deposits of the buried valley. These wells were used to monitor shallow groundwater levels and to obtain samples for chemical analysis. Pumping tests were conducted with the wells to determine hydraulic properties of the major aquifer in both the north and south buried valleys. The hydraulic head was recorded (Appendix VIII), and groundwater samples obtained from August 1977 to August 1978.

During early May 1978, 25 shallow test-holes were

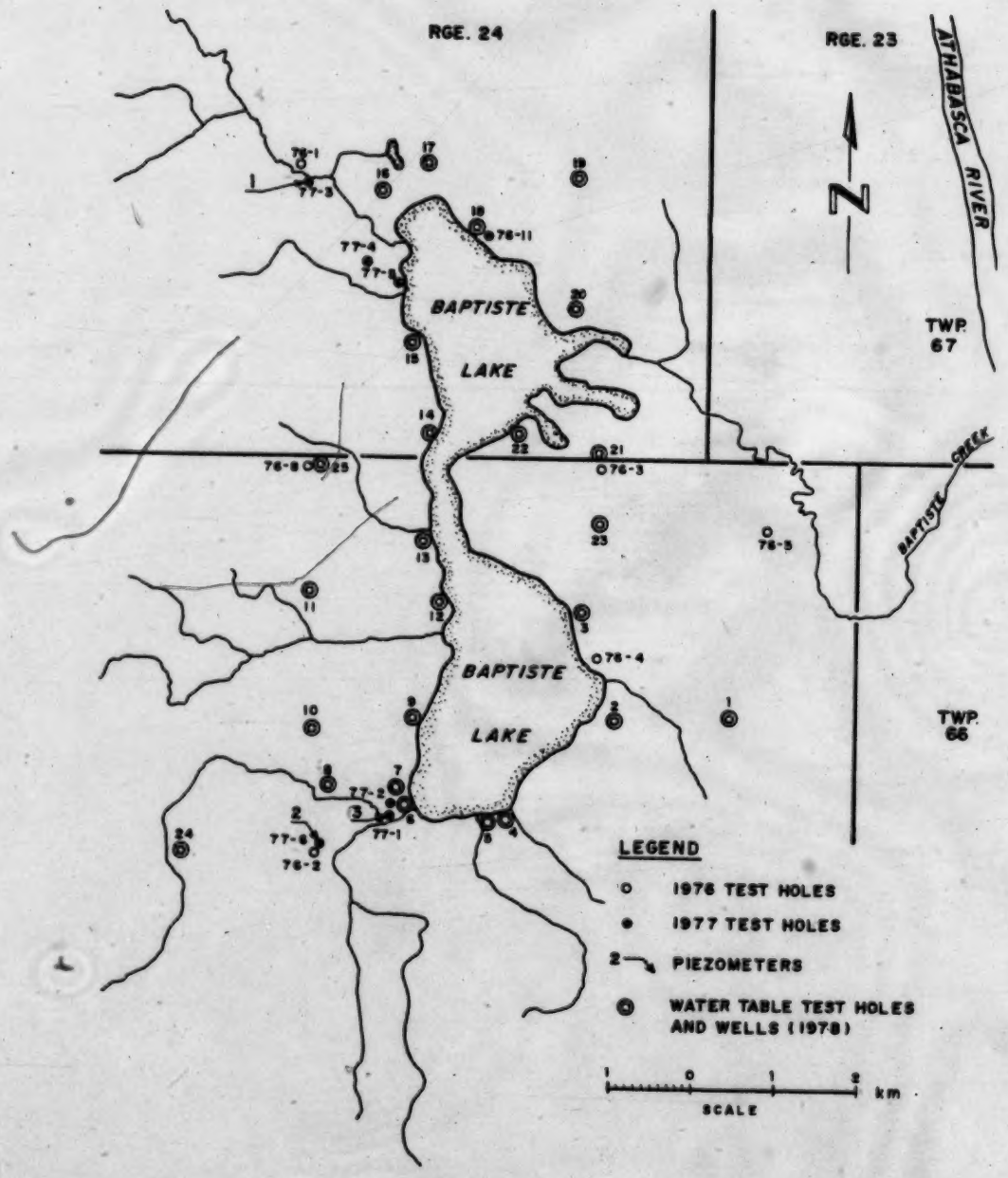


Figure 21. Location of the test holes.

augered. Water table wells were completed at 23 sites (Figure 21). These wells were used to monitor groundwater level fluctuations and chemistry. The results of the shallow drilling program are listed in Appendix VIII. The water table observation wells were completed with a large slotted interval to ensure that the water table was intersected. Once the wells had stabilized, water levels were monitored during the summer and fall of 1978 (Appendix VIII). During the period of study, two sets of water samples were collected for analysis by the Pollution Control Division, Alberta Environment Laboratory, or at the University of Alberta.

Geology

The uppermost bedrock unit underlying Baptiste Lake is the LaBiche Formation (Feniak, 1944; Green, 1972), which is Upper Creataceous in age. It consists of dark greenish-grey marine shale. The hills west of Baptiste lake consist of a younger unit, the Upper Cretaceous Wapiti Formation (Green, 1972), a unit composed of argillaceous sandstone, bentonitic mudstone and coal.

The bedrock topography of the area has been re-interpreted from the studies by Borneuf (1972) and Carlson (1976) to include data from the present test drilling program and from water well logs (Figure 22). Baptiste Lake is situated in a deep bedrock depression which is part of a preglacial buried bedrock valley (Figure 22).

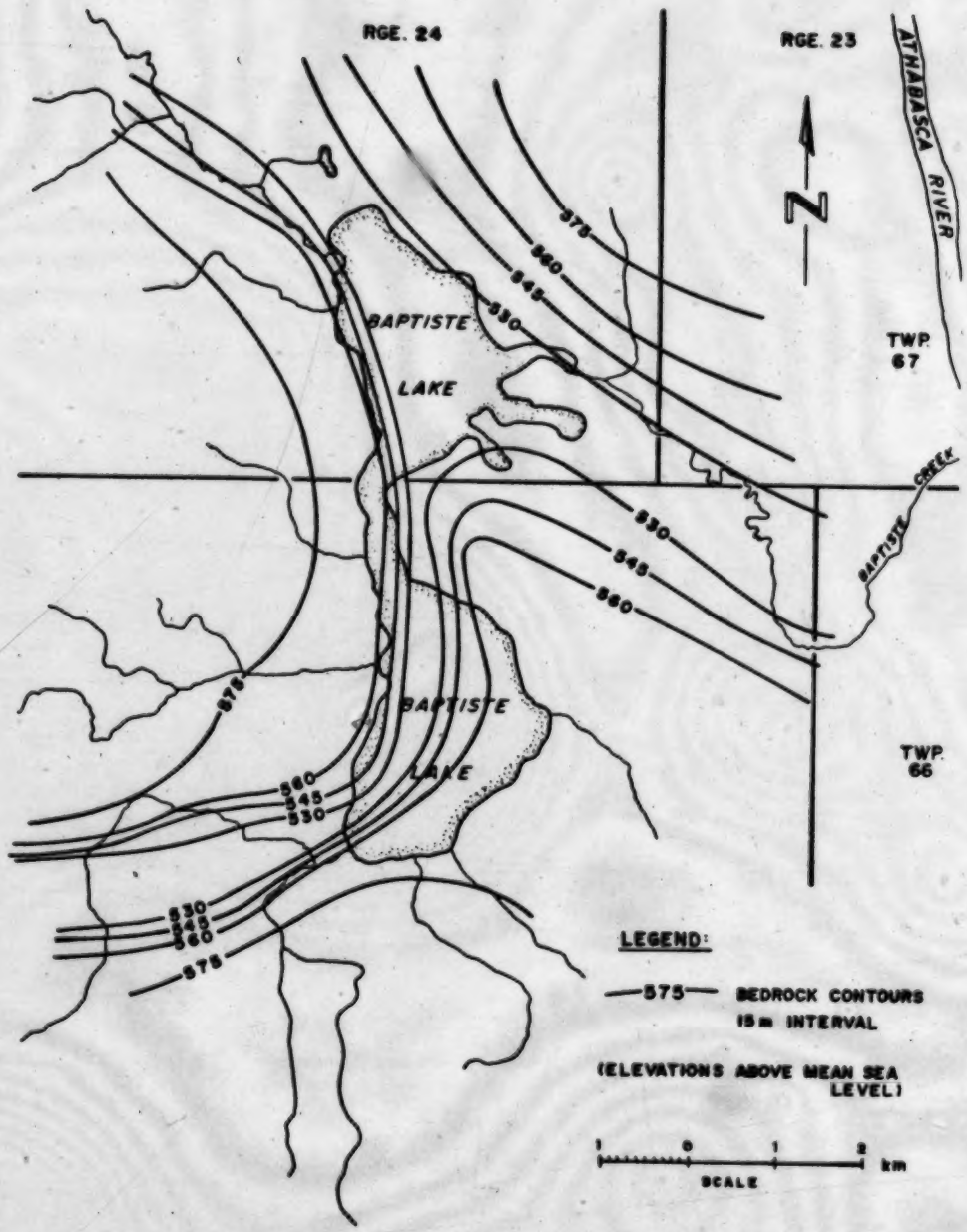


Figure 22. Bedrock topography, Baptiste Lake area.

This valley trends from west to east at an elevation of approximately 525 m above mean sea level (15 m below the lake bottom). Bedrock elevations in the surrounding area typically exceed 575 m above sea level west of the lake and 560 m east.

Preglacial sand and gravel is found resting on the bedrock surface at the base of the buried valleys. These deposits consist of fine sand to medium gravel, and contain a considerable amount of clay.

Quaternary deposits were originally mapped on a very large scale by Kjearsgaard (1972). Additional data from the shallow drilling program and from air photo interpretation facilitated a more detailed interpretation of the surficial geology (Figure 23). The till, lake deposits, alluvium and dune deposits found in the area are often mixed or reworked.

Till is the dominant material. It overlies the bedrock, generally with thicknesses of up to 30 m. However, overlying the preglacial deposits in the bedrock valleys, the till attains thicknesses of up to 100 m. The dark brown-grey to dark grey till has a clay-loam texture with occasional interbeds of sand or gravel. The parent material of the till is the LaBiche Formation (Kjearsgaard, 1972). The till is described by Kjearsgaard (1972) as an ablation or recessional type with associated landforms such as ice contact rings on the west side of the lake and knob and kettle topography near the southeast end of the lake. Along the west shore of Baptiste Lake, the till has been reworked

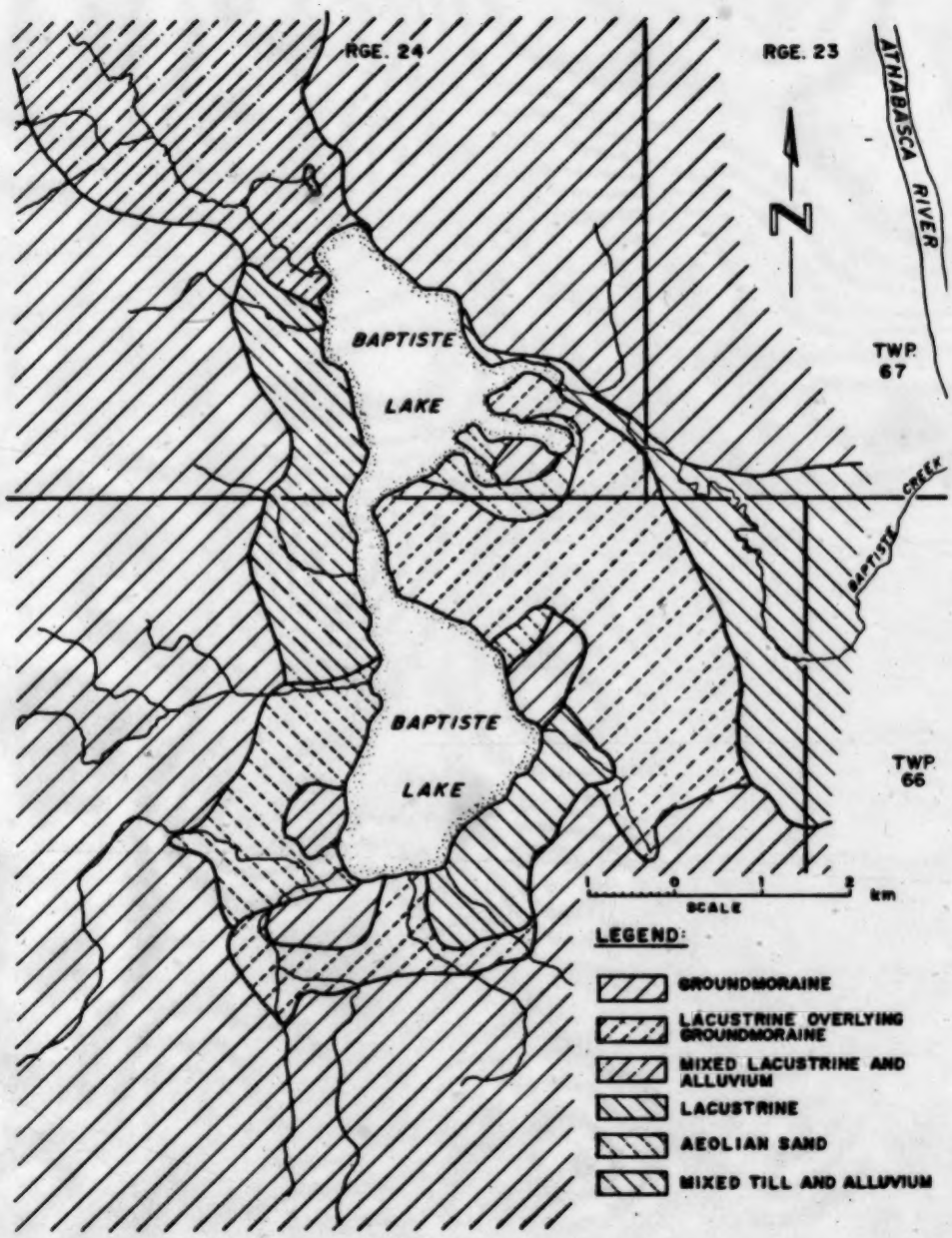


Figure 23. Surficial deposits, Baptiste Lake area.

by glacial ice and melt-water. It is silty and contains some sand lenses.

Lacustrine deposits are found generally as a thin unit (less than 0.5 m) mantling till. In depressions, they can be up to 3 m thick.

Along the northwest portion of the study area which overlies the buried valley, the unconsolidated sediments consist of layers of till, alluvium and silt. At the surface they have often been reworked and mixed, and are cummulatively described in this thesis as alluvium-lacustrine deposits(Figure 23).

Medium to coarse grained, rust-orange aeolian sands are found southwest of the lake and with a minor occurrence on the east side of the south basin. The maximum thickness recorded during this study was 30 m at 1-20-66-24-W4M.

Hydrogeology

The patterns of groundwater flow were investigated using data obtained from the deep and shallow drilling programs, from the piezometers and from existing well logs. However, most test-holes drilled during this study and domestic wells are located close to the lake and the major portion of the western half of the watershed has not been drilled.

Four hydrostratigraphic units have been defined: (1) sand and gravel deposits situated along the base of the buried preglacial valleys, (2) the major till unit, covering

most of the basin, (3) a silty alluvium-lacustrine unit overlying till and, (4) aeolian sands which occupy the smallest portion of the basin. These units correspond to the surficial deposits previously discussed. The Labiche Formation is of little hydrogeological significance. No existing domestic wells are completed in this bedrock unit and test drilling did not define any potential aquifers. The Wapiti Formation, located west of Baptiste Lake, contains more significant yields of groundwater (Borneuf, 1972).

Groundwater flow in the Baptiste Lake area can be studied by examining the hydraulic conductivity of the hydrostratigraphic units. Values of hydraulic conductivity of the buried channel deposits were determined from aquifer tests. Hydraulic conductivities for the other units were obtained by estimation. The till, which probably contributes most of the groundwater to the lake, was estimated to have a hydraulic conductivity in the order of 10^{-6} cm/sec. The hydraulic conductivity of the alluvium-lacustrine deposits is an average for the total thickness of the unit and is estimated to be 10^{-4} cm/sec. The aeolian sands possess the highest hydraulic conductivity, being in the order of 10^{-1} cm/sec. The hydraulic conductivity of the sand and gravel in both the north and south bedrock valleys were found to be approximately $1.2*10^{-4}$ cm/sec and $1.6*10^{-4}$ cm/sec respectively. Thus water movement through the till, including infiltration, is generally quite slow, whereas flow through the aeolian sands will be relatively

rapid.

The water table was found at depths ranging from 0 m to 15 m below ground surface, and fluctuated according to recharge from precipitation. The depth to water was usually greatest in areas of extensive till. Because the uplands west of the lake consist mainly of swamps and muskeg, the water table is at the ground surface. Along the trend of the preglacial valley, the watertable is usually at or near the ground surface.

It is suspected that the main groundwater recharge area for the Baptiste Lake watershed is the upland area to the west and southwest of the lake. Water is either ponded in shallow surface depressions, which drain to the lake, or it slowly percolates into the till. Water in the shallow hydrostratigraphic units primarily discharge to streams or directly to Baptiste Lake. Some water probably percolates to the deeper groundwater systems, which primarily discharge to Baptiste Lake. Groundwater from the deeper till units may possibly flow into the buried channel deposit. The chemistry of groundwater in the buried valley sediments indicates that it probably originates in the Wapiti Formation because of the similarity of the chemistry of groundwaters from these two units.

Water levels at piezometers 1B, 2B and 3B remained relatively constant during the period of study, varying only by a maximum of 1.5 m at piezometer 2B and 2 m at piezometer 1B. The hydraulic head of the wells completed in the buried

valley deposits on the west side of the lake are above the ground surface in all three observation wells and at three domestic wells. However, hydraulic heads in domestic wells completed in these sediments on the east side of the lake, at NW-36-66-24-W4M, are considerably lower. This head loss between piezometers 1B, 2B, 3B, the lake and the wells at NW-36-66-24-W4M, is interpreted as groundwater discharge occuring from the buried valley to the lake and outflow from the lake via the buried valley. On the basis of the shallow groundwater chemistry, it is thought that some groundwater moves upward from the buried valley through the overlying till at the southwest and northwest ends of Baptiste Lake.

Groundwater Chemistry

Chemical analyses were conducted on groundwater samples obtained from wells and from piezometers completed in the surficial deposits (Appendix VII). The chemistry of the shallow groundwater regime exhibits extreme variability with no discernable patterns. This situation is typical of many shallow groundwater systems in Alberta (Schwartz, 1979). However, when the analyses were grouped according to the four hydrostratigraphic units in which the well or piezometer was completed, the mean ionic concentrations, summarized in Table 4, show some patterns.

Groundwaters in the buried valley deposits and the overlying surficial deposits have very different chemical characteristics. Groundwater from the buried valley is

characterized by high concentrations of sodium and low calcium and magnesium. Waters from the surficial materials typically have higher calcium and magnesium concentrations and much lower sodium concentrations. Bicarbonate is the major anion present in both deep and shallow groundwater. The chemistry of the buried valley deposits may be the result of discharge of groundwater from the Wapiti Formation into sand and gravel situated in the buried valley.

Table 4.

MEAN IONIC VALUES OF GROUNDWATER IN THE BAPTISTE LAKE WATERSHED

(all values in mg/L)

Unit		Ca	Mg	Na	K	HCO_3	SO_4	Cl	TDS
Till		98	33	83	5.1	630	74	2	1080
Alluvium-Lac.		103	27	16	3.0	433	51	1	735
Aeolian		119	10	12	5.0	167	18	<1	300
Buried Valley:	N	37	14	357	3.1	687	223	98	1120
	S	<2	2	305	1.6	645	68	24	757

Variability in chemistry is also evident in the groundwater within the buried valleys flowing towards Baptiste Lake. Higher concentrations of all major ions are observed at the north valley as compared to the south. Chloride and sulfate are especially more prevalent in the north valley. Total dissolved solids is approximately 1120 mg/L in the north channel as opposed to with 760 mg/L in the south channel.

Groundwater in the glacial deposits are generally characteristic of shallow groundwaters in the prairies;

being of a calcium-magnesium-bicarbonate type. Analyses of waters from the aeolian sands have the lowest concentrations of dissolved chemical species of any unit. This is especially evident at water table well #10 where the groundwater analyses indicated a total dissolved solids concentration of 57 mg/L. It is thought that these waters are derived from precipitation which has rapidly infiltrated into the sands and has not had a sufficient residence time to dissolve much salt. Groundwater chemistry from the till and alluvium-lacustrine deposits are quite similar. However, the till is generally a few mg/L higher in all ionic species except calcium. In the till, the average sodium and calcium concentrations are almost the same.

Model Study of Baptiste Lake

The principle purpose of any model is in its application to understanding the processes involved in a real system, and ultimately to predicting the responses of a system to various kinds of stresses. In this section, the lake-watershed model is applied to the Baptiste Lake watershed. In particular, this section will consider the use of the model in studying various processes in the lake-watershed system, such as the nature of groundwater inflow to the lake, and in predicting the impact of future cottage development along the shoreline. Finally, data requirements for lake-watershed studies of this type will be discussed in a general way to assess the possibilities for

future model studies.

Baptiste Lake Simulation Parameters

To achieve a satisfactory simulation of any lake-watershed, the model must be able to approximate the hydrologic processes in the basin. The hydrological variables which the model simulates are lake stage, salinity of the lake, outflow from the lake via groundwater and surface water, recharge to the groundwater zone, unsaturated zone moisture, thickness of ice during the winter, surface runoff and groundwater discharge to the lake. Where possible, the parameters required for simulation are taken from real data. However, as indicated previously, some could only be estimated by trial and error. These parameters are discussed in detail in the following pages. Appendix III contains a listing of the Baptiste Lake model input card deck.

The Baptiste Lake watershed was modelled as a single basin or subarea. Neither the accuracy of the field data nor the structure of the model justified an increased complexity of watershed parameters, for example, to account for the twelve streams flowing into the lake.

The Baptiste Lake watershed was divided into eight groundwater storage elements, as illustrated by Figure 24: five shallow and three deep. The elements correspond to the hydrostratigraphic units discussed previously. They are: elements 1 and 2, units which represent the

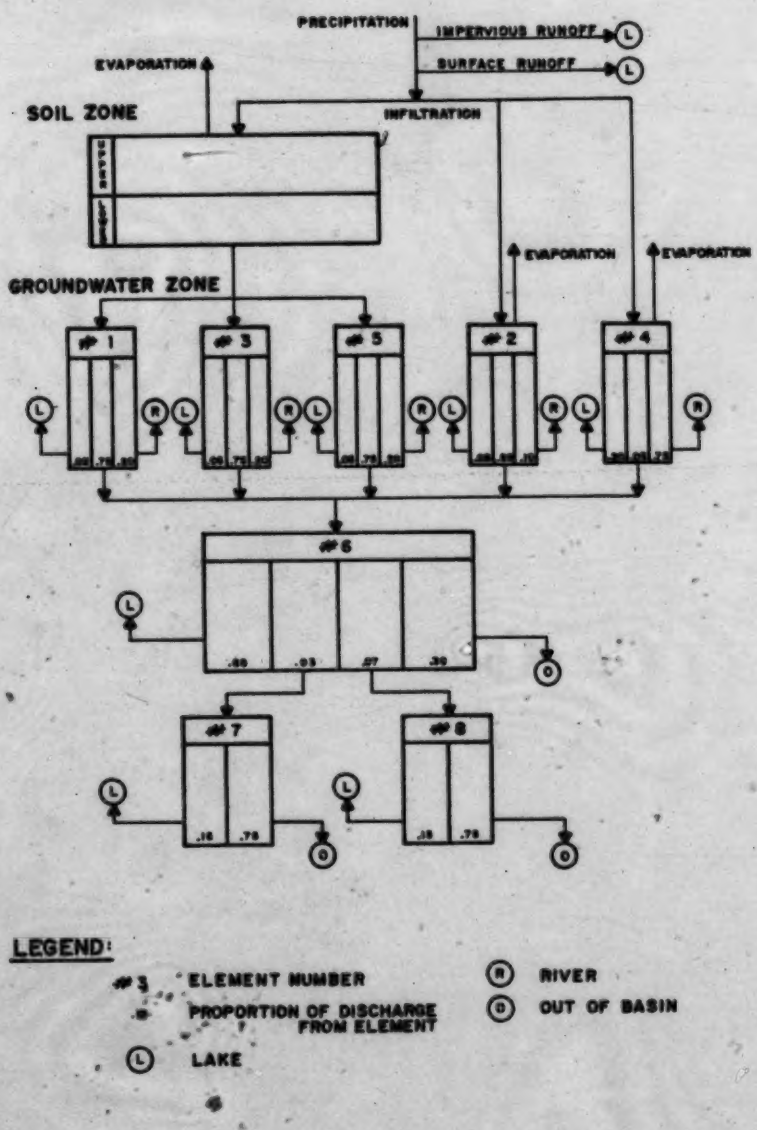


Figure 24. Schematic representation of the Baptiste Lake watershed model.

alluvium-lacustrine deposits with and without an overlying unsaturated zone; elements 3 and 4, which correspond to the shallow till unit, again with and without an overlying unsaturated zone; element 5, an element representing the aeolian sand; element 6, the deep till unit; and two elements, 7 and 8 corresponding to the sand and gravel deposit along the north and south buried valleys, respectively. The percentage of the watershed surface that is occupied by the elements is listed on Table 5.

Table 5.

GROUNDWATER STORAGE ELEMENT PARAMETERS FOR THE SIMULATION OF THE BAPTISTE LAKE WATERSHED

element	% area	salinity	DT	RT	previous g.w. outflow	previous g.w. recharge
1 silt u.z.	15	400 mg/L	1.	1.	0. cm	0. cm
2 silt	2	400 mg/L	1.	1.	0. cm	0. cm
3 till u.z.	46	500 mg/L	1.	1.	0. cm	0. cm
4 till	35	500 mg/L	1.	1.	0. cm	0. cm
5 sand u.z.	2	250 mg/L	1.	1.	0. cm	0. cm
6 deep till	0	600 mg/L	7.	1.	.005 cm	0. cm
7 N. channel	0	1125 mg/L	4.	1.	.001 cm	.001 cm
8 S. channel	0	775 mg/L	4.	1.	.004 cm	.004 cm

The storage delay time coefficients for the groundwater storage elements, previous groundwater outflow from the storage elements, and previous recharge to the elements were obtained by trial and error. Model runs generally commenced

in the spring so that the recharge to the shallow elements and outflow during the previous month, which was the last month of winter, might be assumed to be zero. This assumption was supported in all subsequent runs which showed the outflow and recharge to be almost zero by the end of the last month of winter. Initial estimates of the amount of previous outflow from the deep elements were estimated and then refined by comparing them to discharge calculated during the latter years. Groundwater storage delay time coefficients are parameters which can only be estimated by trial and error. Lower values were initially used for the shallow elements than the deep elements because it was thought that the residence time for groundwater in the shallow elements would be less than the deep elements. The values of delay time, previous groundwater recharge and previous groundwater discharge to give the 'best fit' simulation are listed on Table 5.

Other watershed parameters, such as groundwater discharge from an element, unsaturated zone moisture capacity and initial moisture content, the percentage of the basin which is impervious, and the groundwater recharge rate were first estimated from available data then refined during the later runs. The amount of groundwater discharge from each element that is proportioned to other elements or to the surface waters was first estimated and finally arrived at by trial and error adjustments to the value. The final proportions of discharge are illustrated on Figure 24.

Initial estimates of the upper and lower unsaturated zone moisture capacities, their present moisture content, the maximum allowable recharge to the groundwater zone and the percentage of the basin that is impervious were subsequently refined, producing a better fit to firstly, the fluctations of the lake level and secondly, lake salinity. These values are listed on Table 6.

During the calibration process and sensitivity analysis (Chapter III), it was found that the lake level fluctuations and lake salinity were more sensitive to some parameters than to others. Small changes of the percentage of the basin which is impervious, unsaturated zone moisture capacity and the maximum groundwater recharge rate resulted in particularly sensitive lake changes. For example, a 0.5% change of the impervious cover, or a 0.5 cm variation of the unsaturated zone moisture capacity and the maximum groundwater recharge rate significantly altered the lake system. Parameters that were not very sensitive were the storage delay time coefficient for a groundwater storage element, previous groundwater outflow from an element, previous groundwater recharge to an element, the proportion of groundwater outflow from an element and initial moisture storage in the unsaturated zone. Here, relatively large changes could be made without resulting in significant changes to the lake levels or chemistry.

The salinity of the groundwater storage elements were estimated from chemical analyses studied in the groundwater

chemistry section, and are listed on Table 5. Characteristic salinities of surface runoff and precipitation were determined from analyses collected by the Water Quality Control Branch of Alberta Environment. These values are also presented on Table 6.

Table 6.

BAPTISTE LAKE WATERSHED SIMULATION PARAMETERS

number of subareas: 1
area of the basin: 299.70 km²
percentage of impervious area: 13%

upper unsaturated zone moisture capacity: 5.0 cm
lower unsaturated zone moisture capacity: 10.0 cm
previous upper unsaturated zone moisture: 0.0 cm
previous lower unsaturated zone moisture: 0.0 cm
maximum groundwater recharge rate: 3.0 cm

salinity of precipitation: 10 mg/L
salinity of impervious flow: 10 mg/L
salinity of interflow/overland flow: 100 mg/L

Climatic Variables

Total monthly precipitation and average monthly temperature were obtained from the Athabasca 2 meteorolgy station (Canada Atmospheric Environment Services, 1970 - 1977). The station is located approximately 15 km east of Baptiste Lake. Appendix X lists the precipitation and temperature measurements.

There are many problems associated with trying to measure evaporation from a watershed. For this reason many empirical methods, which are based on measurable climatic

parameters, have been proposed. A simple but very practical method was developed by Thornthwaite (1948) and Thornthwaite and Mather (1955). The formula, based on mean monthly temperature and length of day, (discussed by Gray et al., 1970) is:

$$E_p = 1.62 \left(\frac{10\, T_m}{\phi}\right)^{a} \cdot \Psi \qquad \text{.....(39)}$$

where: E_p = monthly potential evaporation, in cm

T_m = mean monthly temperature, in °C

a = an exponent defined as:

$$a = 6.75 \times 10^{-7} \cdot \phi^3 - 7.71 \times 10^{-5} \cdot \phi^2 + 1.79 \times 10^{-2} \cdot \phi + 0.492 \qquad \text{.....(40)}$$

ϕ = heat index, defined as:

$$\phi = \sum_{i=1}^{12} \left(\frac{T_m}{5}\right)^{1.51} \qquad \text{.....(41)}$$

Ψ = daylight and latitude correction factor

The values of potential evaporation calculated by this method are adjusted for changes in daylight hours and the latitude of the recording station by employing a correction factor provided by Gray et al. (1970).

This method of determining potential evaporation has been selected for use at Baptiste Lake because of its applicability to a watershed where the detailed climatic data that are required by other evaporation formula are not available. More importantly, Laycock (1967, 1968, 1971, 1973) has shown the applicability of Thornthwaite's technique for numerous water-balance studies in the Canadian

prairies. Tests of the various evaporation models have led to the conclusion that this formula produces the most realistic water balance (Laycock, 1971).

The values of mean monthly temperature required in the Thornthwaite formula were obtained from the Athabasca 2 meteorolgical station. The calculated potential evaporation values are listed in Appendix X.

Lake Functions

Lake functions for Baptiste Lake were obtained from the Hydrology Branch of Alberta Environment. These include a capacity-stage curve and an area-stage curve, drawn from a hydrographic survey of Baptiste Lake. The curves and the lake survey are included in Appendix V. The functions that define the two curves were determined to fit the data along the upper portions of the curves as closely as possible because this includes the range of natural lake level fluctuations. The functions are:

Area-Stage Curve

$$S = 552.26 + 8.60\sqrt{A} \qquad \text{.....(42)}$$

Capacity-Stage Curve

$$S = 557.82 + 2.19\times10^{-3}\sqrt{V} \qquad \text{.....(43)}$$

where: S = elevation of the lake surface, in m a.m.s.l.

A = area of the lake surface, in km^2

V = volume of water in the lake, in m^3

A stage-discharge curve for the outlet creek was not available. Surface water outflow from the lake was calculated according to a method discussed by Wigham (1970):

$$Q_o = \frac{V_o}{K_l} \cdot e^{-T_l/K_l} \qquad \text{.....(44)}$$

where: Q_o = surface water outflow, in m^3

V_o = volume of the lake above the surface water outlet level, in m^3

T_l = time of uniform recharge to the lake, in months

K_l = storage delay time of the lake, in months

The lake surface elevations were recorded by the Water Survey of Canada. All initial parameters describing the lake are listed in Table 7.

Table 7.

BAPTISTE LAKE SIMULATION PARAMETERS

surface outflow elevation: 577.78 m
initial lake elevation: 576.80 m
initial lake salinity: 200 mg/L
lake recharge time: 0.5 months
lake storage delay time: 1.0 month
lake discharge via groundwater: 4.0 cm
initial ice thickness: 100 cm

The Simulation of Baptiste Lake

A satisfactory simulation of lake surface levels and lake salinity fluctuations at Baptiste Lake was achieved with the model. A comparison of the actual field measurements of lake level and salinity with the model calculations are illustrated on Figure 25 and Figure 26 respectively.

Although the actual and calculated values are not always the same, the patterns of fluctuation follow the same trends. The discrepancies between the two sets of results is thought to be caused by: (i) model error, (ii) data error, and, (iii) inaccuracy of hydrologic functions.

Model error is probably the most important and is attributed to the simplicity of the model. For example, the geology of the watershed has been partitioned into only eight hydrostratigraphic units. Variability in some surface features, such as vegetation, have not been considered, and it is assumed that spring runoff commences at the same time each year. Also, the lake is not considered to be stratified, precipitation of salts in the lake is assumed not to occur, and groundwater salinity assigned to the storage elements is an averaged general value.

Data errors result from not having a meteorolgical station within the watershed. Precipitation, potential evaporation and temperature are measured 15 km away at Athabasca. In addition, there are no appropriate ways of

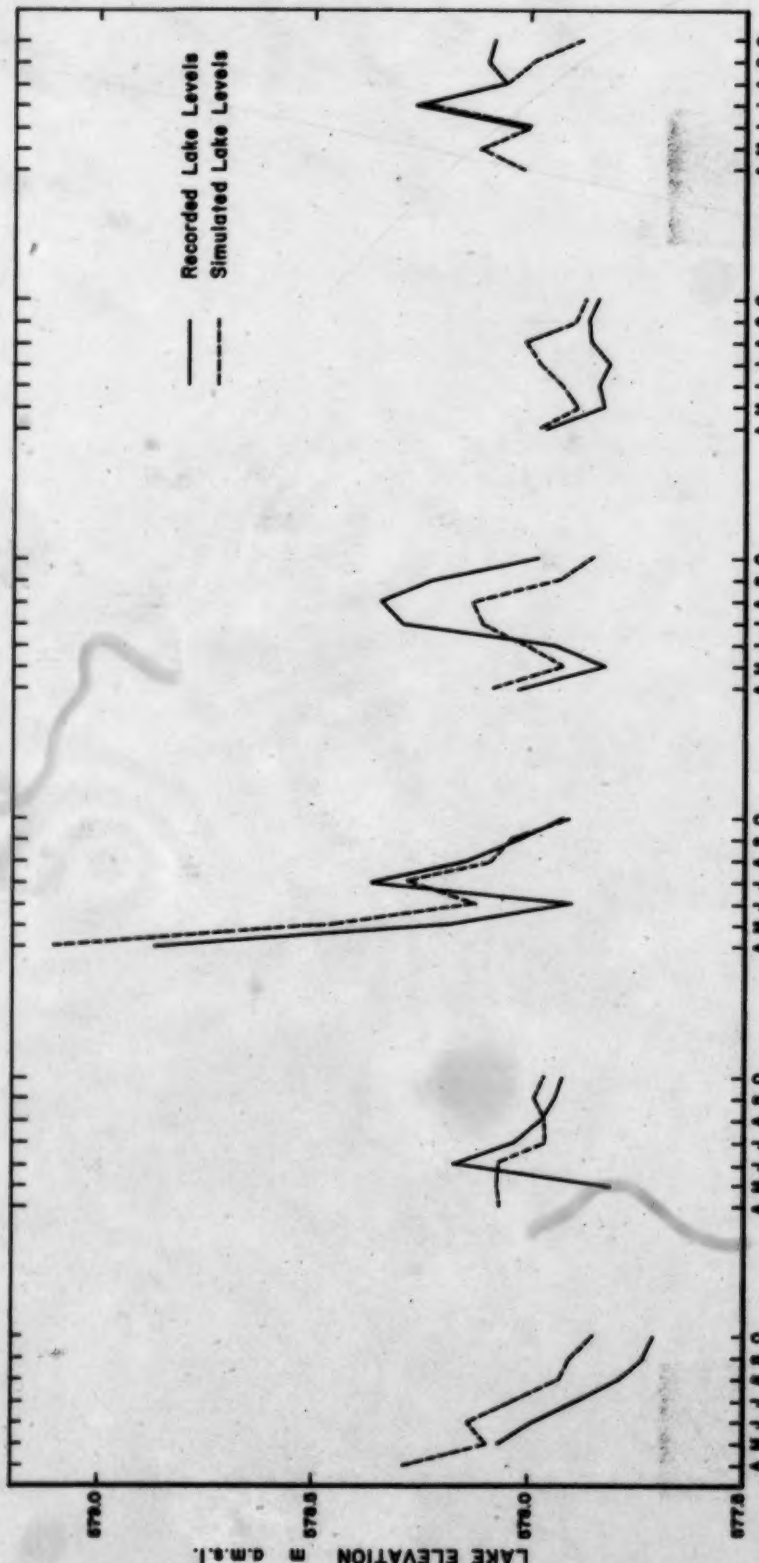


Figure 25. Simulation of Baptiste Lake surface elevations.

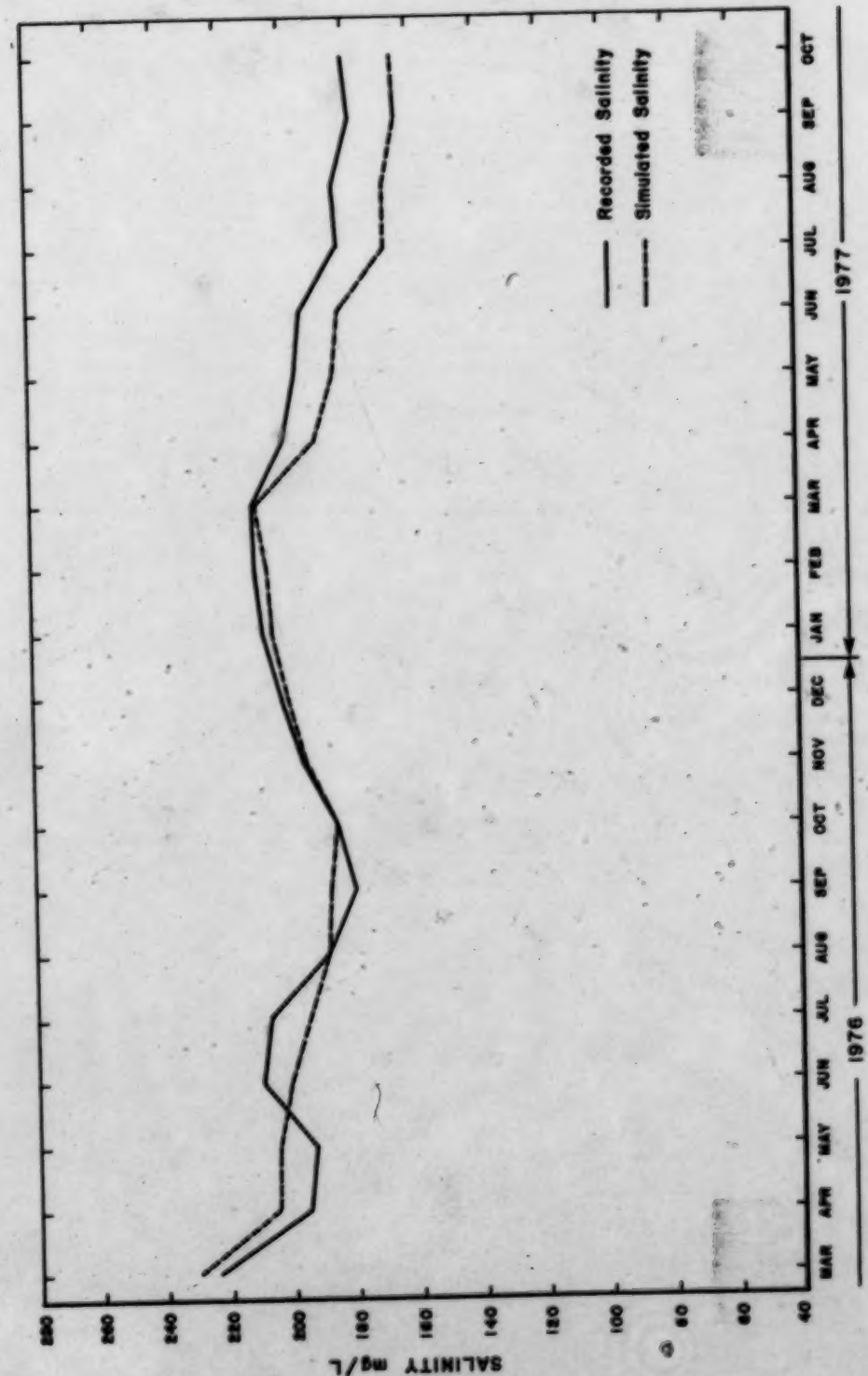


Figure 26. Simulation of Baptiste Lake water chemistry.

determining whether the averaged groundwater chemistry values are a reasonable characterization of the complex natural situation. However, the sensitivity analyses indicate that these data errors should not be a significant source of error in the simulation.

The last group of errors, the inaccuracy in the hydrologic functions, also cause a significant deviation of the model calculations from actual values. The surface water outflow probably causes the single largest source of error. A stage-discharge curve was not available for the outlet creek. However, the function used to estimate surface water outflow was thought to provide a reasonable estimate because it has been shown by Wigham (1970) to be an acceptable formula for calculating discharge from a lake. Other problems will arise in the model study from applying an inaccurate function to the stage-area and stage-capacity curve. While it is difficult to assess the accuracy of the lake survey, it can only be considered approximate.

Differences between real and simulated lake levels could occur also as a result of changes to the outlet creek, resulting in increased or decreased outflow from the lake. For example, the outlet creek could have been blocked by beaver dams or slumping of its banks (Water Resources Mangement Division, 1979) causing higher than predicted lake levels during the latter part of 1977. A bridge replaced the existing culverts during the fall of 1970 and the stream embankment was removed in the summer of 1971 (Water

Resources Management Division, 1979). Thus, possibly explaining why the model predicted higher lake levels than were actually recorded during 1972.

The simulation results point to the importance of groundwater in the hydrologic balance of Baptiste Lake. Table 8 lists the percentages of the various inflows to, and outflows from Baptiste Lake, for the period 1972 to 1977, calculated with the model. During this time, the groundwater contributed an average of 13% of all recharge to the lake.

Table 8.

PROPORTIONS OF THE HYDROLOGIC COMPONENTS AT BAPTISTE LAKE

	% inflow:			% outflow:		
	g.w.	s.w.	prec.	g.w.	s.w.	evap.
1972	22	68	10	13	72	15
1973	13	68	19	14	70	16
1974	18	74	8	8	83	9
1975	9	74	17	14	69	17
1976	7	76	17	18	60	22
1977	9	75	16	13	72	15

The reader is cautioned that Table 8 and the given value of 13% for the average groundwater recharge to the lake are only an estimates. These values are based on over 50 trial runs; not just one simulation. And, while these numbers are as accurate as the model and the data permits, the values are calculated only to provide the reader with insight into the significance of groundwater recharge to Baptiste Lake.

To further verify this result, the watershed was

modelled assuming no groundwater discharge to the lake and no discharge from the lake via groundwater. All water was assumed to enter the lake as either surface runoff or as precipitation falling directly on the surface. The resulting lake level fluctuations, Figure 27, are similar to the actual values. However, a closer fit can be obtained when groundwater component of the watershed budget is included. Lake salinity, without groundwater input, is less than half that as when groundwater discharge is included in the simulation (Figure 28). Also, the salinity fluctuations that exist at Baptiste Lake are not shown. These results present a striking illustration of the importance of the groundwater contribution to Baptiste Lake.

Further Study at Baptiste Lake

In the previous two sections, a simple hydrologic model simulated lake level and salinity fluctuations at Baptiste Lake. Now, a preliminary extension is undertaken to evaluate one possible impact of watershed development at Baptiste Lake.

This study is concerned with the possible impact that a new cottage development, situated on the shore of Baptiste Lake, will have on the lake. The cottage development was simulated by including a shallow groundwater element which covers approximately 5% (15 km^2), of the surface of the watershed, having hydrogeological characteristics of the shallow till storage element with no overlying unsaturated

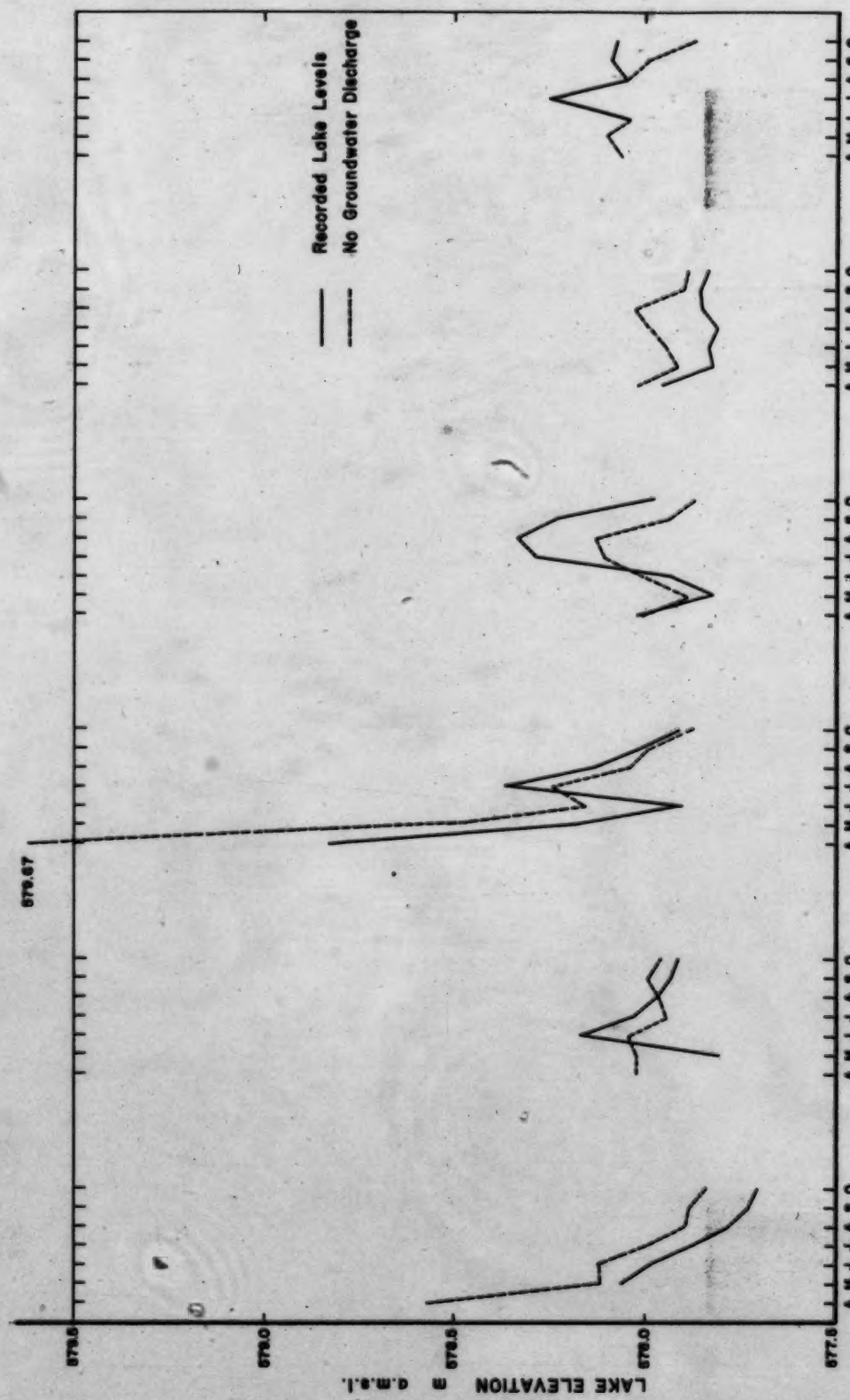


Figure 27. Various simulations of Baptiste Lake levels.

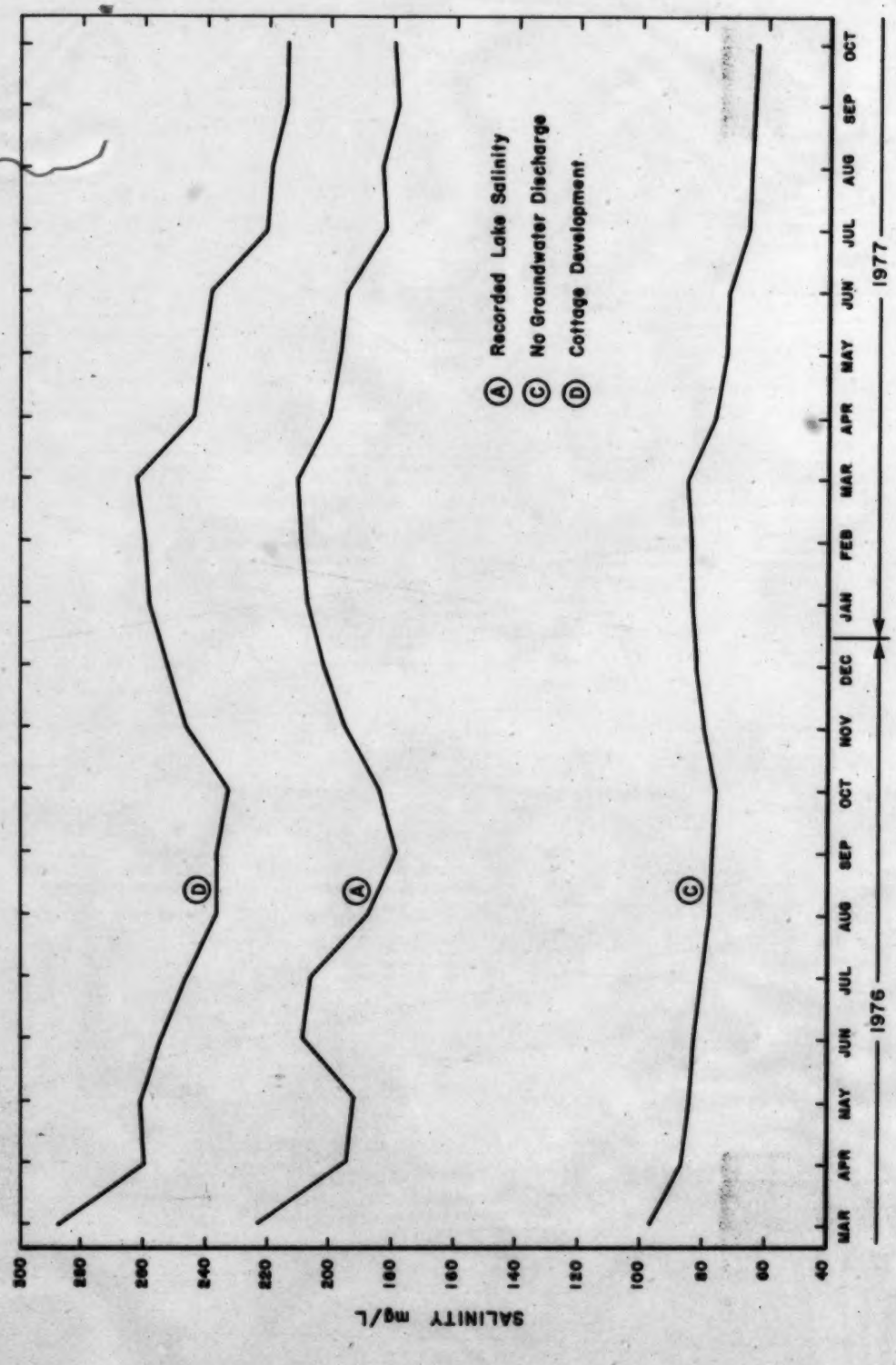


Figure 28. Various simulations of Baptiste Lake chemistry.

zone, (element #4). A total dissolved solids content of 2000 mg/L, approximately 10 times that of the lake, is designed to reflect an increased chemical parameter over background concentrations. While salinity may not be the best chemical parameter to simulate cottage development, it is used here for two reasons. Firstly, salinity is the only chemical parameter routed through this model and, secondly, the purpose of this simulation is only to illustrate in a general way the effect that any contaminant may have on lake chemistry. All groundwater discharging from the element flows directly to the lake. Other element parameters remain the same as defined for element #4.

The resultant change in the lake water quality, Figure 28, is that the salinity of the lake increased by approximately 50 mg/L, thus indicating a significant rise in lake salinity over background conditions. This simulation assumed the worst hydrologic conditions, such as no overlying unsaturated zone and all water is discharged directly to the lake. With no unsaturated zone, the water table is at the ground surface and all contaminants will immediately enter the groundwater system.

It can probably be assumed that a development would be situated in an area where the water table is well below the ground surface, presenting the possibility of contaminant attenuation in the unsaturated zone. Another analysis was conducted with the development located on the same till unit, but included an overlying unsaturated zone. This

resulted in restricted infiltration to the groundwater zone, and hence, a negligible influence on lake water quality.

However, dealing with total dissolved solids as a parameter to study lake contamination from cottage developments, may be misleading. It should be remembered that this analyses shows that a single parameter, in high concentrations in the effluent above background lake values, could have a significant influence on the chemistry of the lake.

V. CONCLUSIONS

The model developed in this thesis provides a useful means of simulating the hydrological and hydrochemical processes of a lake-watershed system. The model is simple and is designed to be used when only an estimation of the various hydrologic components of the watershed is required. Only a limited amount of basic physical, climatic, hydrological and hydrochemical data is required by the model for hydrological simulation of a lake-watershed system.

It is possible to use this kind of model to learn more about the processes and parameters controlling the physical and chemical hydrology of lakes in a prairie setting. Sensitivity analyses of actual or hypothetical cases can lead to a better understanding of how the system functions. Although caution is warranted, generalizable results for sets of lake systems should be possible from the analyses. Sensitivity analyses of hypothetical lake-watershed systems showed:

1. If it were physically possible to alter a lake by concentrating the same volume of water into a lake with a smaller surface area, the salinity of the lake should decrease and lake levels rise. The reason for this occurrence is that evaporation exhibits less of a influence on a lake with a small surface area and a

greater influence over lakes with a large surface area.

2. The analysis of the hypothetical lake-watershed showed that if the lake volume was increased, without a corresponding enlargement of its surface area, the same results as above are obtained.
3. The study of the formation of ice, an important process on prairie lakes, indicated that the more water that is taken up from the lake during the formation of ice, the greater the salinity of the lake (the salinity fluctuations in shallow lakes are greater than in deep lakes, both containing equal volumes of water).
4. Small variations in groundwater chemistry or large variations over a part of the watershed did not significantly alter the salinity of the hypothetical prairie lake. Large increases or decreases in the quality of groundwater over the entire watershed should, however, alter the salinity of the lake.
5. The unsaturated zone, primarily controls the amount of water percolating to the groundwater zone and hence, indirectly influences the amount of groundwater that is discharged to a lake. Decreasing the unsaturated zone moisture capacity in the test watershed caused increased surface runoff and groundwater discharge, which resulted in higher lake levels and salinity.
6. As the proportion of a watershed that is covered by an unsaturated zone decreases, the amount of groundwater recharge increases. Hence, the volume of groundwater

that discharges to the lake is increased, and the quality of the lake water tends towards that of the groundwater.

7. Increasing the area of this hypothetical watershed that is impervious, for example by urbanization, causes precipitation to flow directly to the lake, decreasing the lake salinity which increases fluctuations of lake levels, and generally increases the lake stage.
8. Variations in precipitation and potential evaporation did not cause large fluctuations in lake levels and salinity in the large watershed used in the sensitivity analysis, but did cause significant deviations in the small lake-watershed. The division between large and small watersheds is estimated to be near 100 km^2. In particular, under-estimating precipitation or over-estimating potential evaporation caused a much larger variation than if both parameters were either over-estimated or under-estimated. The major generalization which may be drawn from this study is that precipitation and potential evaporation exhibit a greater influence on lake levels and salinity in a small watershed than groundwater discharge. The opposite is true in a large lake-watershed.

Modelling the Baptiste Lake watershed has been a useful aid for studying hydrologic processes in this basin. The model has only been applied to this one watershed but its implications are that it can successfully be used for

studying the water balance of many prairie lake-watershed.

In the case of Baptiste Lake, the model was able to simulate, with a reasonable degree of accuracy, a two year record of water levels and chemistry. Examination of the relative importance of various components of the hydrologic cycle of the lake showed that groundwater inflow probably constitutes a significant proportion of all recharge to the lake, which was calculated to be an average of 13%. A model of a lake-watershed system can be used to study various processes and the impact of changes to the watershed.

A further capability of this model is to extend a simulated lake record, such as was done at Baptiste Lake, to predict future changes in the watershed. This use of the model is particularly useful for application to watershed development, changes in climatic patterns or examining the past natural history of the lake.

This model study has only examined a few of the numerous natural and man-made processes that govern lake water chemistry and level fluctuations. The results obtained in this thesis indicate that further study of watersheds with this model is justified and development of the model is warranted. Such developments could include: the expansion of the model to study watershed parameters in more detail, the development of functions to stratify lakes and to allow for precipitation of salts from lake water, and accounting for chemical reactions involving individual nutrients as they are routed through watersheds to lakes.

REFERENCES

Ayers, H.D.; 1970; Basin Yield; Section X of Handbook on the Principles of Hydrology; Editor-in-Chief: D.M. Gray; Water Information Centre Inc.; pp. 10.1-10.20.

Borneuf, D.; 1973; Hydrogeology of the Tawatinaw Area, Alberta, NTS 83I; Alberta Research Council Report 72-11.

Carlson, V.A.; 1976; Bedrock Topography of the Tawatinaw Map Area, N1S 83I, Alberta ; Alberta Research Council Map.

Canada Atmospheric Environment Services; 1970-1977; Monthly Records, Meteorological Observations in Canada; Fisheries and Environment Canada.

Crawford, N.H., and R.K. Linsley; 1966; Digital Simulation in Hydrology: Stanford Watershed Model IV; Dept. of Civil Eng., Stanford Univ., Tech. Rep. No. 39.

Crawford, N.H., and A.S. Donigian; 1973; Pesticide Transport and Runoff Model for Agricultural Lands; Office of Reasearch and Development, U.S. Envir. Protection Agency, Rep. No. EPA-660/2-74-013.

Crowe, A.; 1978; Baptiste Lake Groundwater Investigation: Preliminary Report; Alberta Environment, Environmental Protection Services, Earth Sciences Division Report.

Dooge, J.C.I.; 1960; The Routing of Groundwater Recharge through Typical Elements of Linear Storage; Int. Assoc. of Sci. Hydrology General Assembly of Helsinki I.U.G.G.; Publ. No. 52, pp. 286-300.

EPEC Consulting Ltd.; 1976; Cooking Lake Area Study, Vol. I: Formulation of Management Alternatives; Report prepared for the Cooking Lake Area Study Management Committee, Planning Division, Alberta Environment.

Feniak, M.; 1944; Athabasca - Barrhead Map Area, Alberta; C.S.C. Paper 44-6; Can. Dept of Mines and Resources, Mines and Geology Branch.

Fertuck, L.J., J.W. Spyker and W.H.W. Husband; 1970; A Numerical Method for Estimating Ice Growth as a Function of Air Temperature, Wind Speed and Snow Cover; Proc. Thrd. Western Can. Heat Transfer Conf., Edmonton, Alberta, May 28-29, 1970.

Fields, D.E. and S.B. Watson; 1975; OPTRM - A Hydrologic Transport Model with Parameter Optimization; Oak Ridge National Laboratory, Rep. ORNL-NSF-EATC-14.

Fritz, P. and H.R. Krouse; 1973; Wabamun Lake Past and Present: An Isotope Study of the Water Budget; Proc. of the Symp. on the Lakes of Western Canada, 1973, Edmonton, Canada; Pub. No. 2, Univ. of Alberta Water Resources Centre., pp. 244-258

Gray, D.M., G.A. McKay and J.M. Wigham; 1970; Energy, Evaporation and Evapotranspiation; Section III of Handbook on the Principles of Hydrology; Editor-in-Chief: D.M. Gray; Water Information Centre Inc., pp. 3.54-3.61.

Green, R.; 1972; Geological Map of Alberta; Alberta Reaseach Council Map No. 35.

Gull Lake Task Force; 1970; Gull Lake Study, Vol I; Report prepared for the Gull Lake Co-ordinating Committee, Water Resources Division, Alberta Dept. of Agriculture.

Huff, D.O.; 1968; Simulation of the hydrologic Transport of Radioactive Aeresols; Ph.D. thesis, Stanford Univ.

Ingersoll, L.R., O.J. Zobel and A.C. Ingersoll; 1948; Heat Conduction, with Engineering and Geological Applications; McGraw - Hill publishers.

Kjearsgaard, A.A.; 1972; Soil Survey of the Tawatinaw Map Sheet (83I); Alberta Soils Survey No. 29.

Laycock, A.H.; 1967; Water Defeciency and Surplus Patterns in the Prairie Provinces; Prairie Provinces Water Board, Prairie Farm Rehabilitation Administration Rep. No. 13.

-----; 1968; Water Balance of the Gull Lake Basin, A System Analysis for the Period 1921-1968; Report for the Red Deer Regional Planning Commission.

-----; 1973; Lake Level Fluctuations and Climatic Variation in Central Alberta; Proc. of the Symp. on the Lakes of Western Canada, 1973, Edmonton, Canada; Pub. No. 2, Univ. of Alberta Water Resources Centre., pp. 38-98.

-----; 1971; Water Balance in the Cooking Lake Region; Presentation to the Public Hearings of the Environmental Conservation Authority on Cooking Lake, Edmonton.

Linsey, R.K., M.A. Kohler and J.L.H. Paulhus; 1975; Hydrology for Engineers; 2nd Edition, McGraw - Hill publishers.

Nursall, J.R., J.B.Nuttall and P. Fritz; 1971; The Effect of Thermal Effluent on Lake Wabamun; XVIII Limnological Congress, Leningrad, 1971.

Patterson, M.R. et al.; 1974; A User's Manual for the FORTRAN IV Version of the Wisconsin Hydrologic Transport Model; Oak Ridge National Laboratory, Rep. ORNL-NSF-EATC-7.

Penman, H.L.; 1948; Natural Evaporation from Open Water, Bare Soil and Grass; Proc. Royal Society of London, Series 193a, pp. 120-145.

Planning Division, Alberta Environment; 1979; Sylvan Lake Regulation Study; Report prepared for the Red Deer Regional Planning Commission.

Pounder, E.R.; 1965; Physics of Ice; Pergamon Press.

Prairie Provinces Water Board; 1952; Evaporation from Lakes and Reservoirs on the Canadian Prairies: A Study Based on 30 Years of Meteorological Records, 1921-1950; Report #5.

Saskatchewan-Nelson Basin Board; 1972; Water Supply for the Saskatchewan-Nelson Basin, Appendix 4: Hydrology, Vol. 1.

Schwartz, F.W. and D.N. Gallup; 1978; Some Factors Contolling the Major Ion Chemistry of Small Lakes: Examples From the Prairie Parkland of Canada; Hydrobiolgoia, Vol. 58, No. 1, pp. 65-81.

Schwartz, F.W.; 1979; Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta; Report prepared for the Alberta Oil Sands Environmental Research Program; Project HG1.1, AOSERP Report 48.

Stanley and Associates; 1974; Cooking Lake Study, Vol. 2: Water Inventory and Demands; Report prepared for the Cooking Lake Area Study Management Committee, Planning Division, Alberta Environment.

Thornthwaite, C.W.; 1948; An Approach Towards a Rational Classification of Climate; Geographical Review, Vol. 38., No. 1., pp. 55-94.

Thornthwaite, C.W. and J.R. Mather; 1955; The Water Balance; Laboratory of Climatology, Publ. in Climatology, Vol. 8, No. 1.

Trew, D.O., D.J. Beliveau and E.I. Yonge; 1979; Baptiste Lake Study Summary Report; Water Quality Control Branch, Pollution Control Division, Alberta Environment.

Ward, R.C.; 1975; Principles of Hydrology; McGraw - Hill publishers.

Water Quality Control Branch; 1977; Baptiste Lake Study Proposal; Pollution Control Division, Alberta Environment.

Water Resources Management Division; 1979; Baptiste Lake 66-24-W4, correspondence file: file #13011; Alberta Environment.

Wigham, J.M.; 1970; Peak Flow - Rainfall Events; Section VIII of Handbook on the Principles of Hydrology; Editor-in-Chief: D.M. Gray; Water Information Centre Inc., pp. 8.47-8.64.

APPENDIX I

MODEL USER'S GUIDE

Dimensioning of Arrays

There are several subscripted variables used in the program and these must be dimensioned to the correct array size, as indicated in the following:

```
REAL LKSTG,LKVOL,ICE,ICEF,SUB(10),TITLE(20),
     P(nr),PE(nr),AE(nr),TEMP(nr),INFILT(ns),CIMP(ns),
     CSRO(ns),INTR(ns),PCTIMP(ns),ARSUB(ns),RGW(ns),
     RGWMAX(ns),QGWLKT(ns),USZMP(ns),CGWLK(ns),USZM(ns),
     USZMAX(ns),LSZMP(ns),LSZM(ns),LSZMAX(ns),CRV(ns),
     QINTR(ns),QRVT(ns),QIMP(ns),QGWRV(ns,ne),RELM(ns,ne),
     RELMP(ns,ne),PCTAR(ns,ne),QGW(ns,ne),QGWP(ns,ne),
     S(ns,ne),SP(ns,ne),CGW(ns,ne),QGWLK(ns,ne),DT(ns,ne),
     RT(ns,ne),C0(ns,ne),C1(ns,ne),C2(ns,ne),C3(ns,ne),
     C4(ns,ne),C5(ns,ne),PCTELM(ns,ne,6)

INTEGER*2 NOPP(ns,ne),TOELM(ns,ne,6),NGWE(ns)

LOGICAL*1 NEGREC(ns,ne),REPREC(ns,ne),NEGQGW(ns,ne),
          ELEMAM(7)
```

where: ns = number of subareas
nr = number of records
ne = number of groundwater storage elements in each subarea

User Supplied Functions

Three functions are required to be included at the end of the program by the model user. These are:

AREALK(lkstg) - A function used to calculate the surface area of a lake in km², given a lake stage in m above a datum.

ELEVLK(lkvol) - A function which calculates the stage of a lake in m above a datum, given the volume of water in the lake in m³.

OUTFLO(lkstg) - A function which calculates the surface water outflow from a lake in m³, given the lake stage in m above a datum.

VOLLK(lkstg) - This function finds the volume of water in the lake, in m³, given the lake stage in m above a datum.

The calling parameters for the subroutines are:

lkstg = elevation of the lake, in m above a datum
lkvol = the volume of water in the lake, in m³

Input Variables

initial program parameters:
- TITLE :title of data set
- NREC :number of records
- NSUB :number of subareas

subarea parameters:
- ARSUB :area of a subarea (km)
- PCTIMP :fraction of subarea which is impervious ($0 \leq$ PCTIMP ≤ 1)
- NGWE :number of groundwater storage elements in a subaraea
- EGWMAX :maximum allowable recharge from the unsaturated zone to the groundwater zone, in a subarea (cm)

initial lake parameters:
- SWOL :surface water outlet elevation (m above a datum)
- LKSTG :initial elevation of the lake surface (m above a datum)
- ICE :initial ice thickness on the lake surface (cm)
- SNOW :initial depth pf snow cover on the lake (cm)
- DTFLK :storage delay time for lake (months)
- ETFLK :duration of recharge to lake (months)
- TEMPP :average monthly air temperature of the previous month (°C)

unsaturated zone parameters:
- USZMAX :maximum allowable moisture storage in the upper unsaturated zone (cm)
- USZMP :present moisture content of the upper unsaturated zone (cm)
- LSZMAX :maximum allowable moisture storage in the lower unsaturated zone (cm)
- LSZMP :present moisture content of the lower unsaturated zone (cm)

groundwater element parameters:
- ELENAM :7 character identifier for a groundwater storage element
- DT :storage delay time (months)
- ET :time or recharge to an element (months)
- RELMP :recharge to an element during the previous month (cm)
- QGWP :groundwater discharge from an element during the previous month (cm)
- REPREC :check to see if recharge from precipitation or from the unsaturated zone is allowed (T or F)
- NEGREC :test to determine if evaporation may occur from an element (T or F)
- NEGQGW :check to determine whether recharge can originate from a surface water body (T or F)

PCTAR :fraction of outflow from an element that is routed to other elements or the surface ($0 \leq$ PCTAR ≤ 1)
NOPP :number of divisions of an element ($0 \leq$ NOPP ≤ 1)
PCTELM :portion of discharge from an element that is routed according to NOPP ($0 \leq$ PCTELM ≤ 1)
TOELM :element number or surface water body to which groundwater outflow is routed

chemistry parameters:
CP :water quality of precipitation (mg/L)
CLK :initial salinity of the lake (mg/L)
CIMP :salinity of flow from impervious areas (mg/L)
CSRO :salinity of surface runoff (mg/L)
CGW :salinity of a groundwater storage element (mg/L)

climatic variables:
TEMP :average monthly air temperature (°C)
PE :total monthly potential evaporation (cm)
P :total monthly precipitation (cm)

Input Card Instructions

The variables input into the program must conform to the following cards, order, format and columns:

CARD #	VARB.#	VARIABLE	FORMAT	COLUMNS
1	1	TITLE	20A4	1 - 80
2	1	NREC	I5	1 - 5
	2	NSUB	I5	6 - 10
	3	CP	F10.0	11 - 20
	4	TEMPP	F5.0	21 - 25
	5	ICE	F5.0	26 - 30
	6	SNOW	F5.0	31 - 35
3	1	LKSTG	F10.0	1 - 10
	2	SWOL	F10.0	11 - 20
	3	CLK	F10.0	21 - 30
	4	DTFLK	F10.0	31 - 40
	5	RIFLK	F10.0	41 - 50
	6	GWOLK	F10.0	51 - 60

CARD #	VARB.#	VARIABLE	FORMAT	COLUMNS
4[1]	1	ABSUB	F10.0	1 - 10
	2	RGWMAX	F10.0	11 - 20
	3	CIMP	F10.0	21 - 30
	4	CSRO	F10.0	31 - 40
	5	PCTIMP	F5.0	41 - 45
	6	USZMAX	F5.0	46 - 50
	7	LSZMAX	F5.0	51 - 55
	8	USZMP	F5.0	56 - 60
	9	LSZMP	F5.0	61 - 65
	10	NGWE	I5	66 - 70
5[2]	1	ELEMAM	7A1	1 - 7
	2	REPREC	L1	8
	3	NEGREC	L1	9
	4	NEGQGW	L1	10
	5	DT	F5.0	11 - 15
	6	RT	F5.0	16 - 20
	7	QGWP	F5.0	21 - 25
	8	RELMP	F5.0	26 - 30
	9	PCTAR	F5.0	31 - 35
	10	CGW	F10.0	36 - 45
	11	NOPP	I5	46 - 50
6[3]	1	PCTELM	6F5.0	1 - 5, 6 - 10,...
	2	TOELM	6I5	31 - 35, 36 - 40,...
7[4]	1	P	12F5.0	1 - 5, 6 - 10,...
	2	PE	12F5.0	1 - 5, 6 - 10,...
	3	TEMP	12F5.0	1 - 5, 6 - 10,...

notes: [1]: 1 card for each subarea, followed by;
[2]: 1 card for each element, followed by;
[3]: all 6 PCTELM and TOELM values on 1 card
[4]: 12 records per card, followed by more of the same record if required

APPENDIX II

PROGRAM LISTING

```
C          ALLAN CROWE                                                          1
C          GRAD STUDIES, GEOLOGY                                                2
C          UNIVERSITY OF ALBERTA                                                3
C          EDMONTON, ALBERTA                                                    4
C                                                                               5
C          PROGRAMMED: JUNE 1979                                                6
C                                                                               7
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC  8
C                                                                               9
C HYDROLOGICAL AND HYDROCHEMICAL BALANCE OF LAKE-WATERSHED SYSTEM               10
C                                                                               11
C   BAPTISTE LAKE MODEL AND FUNCTIONS                                           12
C                                                                               13
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC 14
C                                                                               15
C DEFINITION OF VARIABLES                                                       16
C                                                                               17
C    AE      = ACTUAL EVAPOTRANSPIRATION (CM)                                   18
C    ARLK    = LAKE AREA (KM2)                                                  19
C    ARSUB   = AREA OF SUBAREA (KM2)                                            20
C    CGW     = CONCENTRATION OF GROUNDWATER (MG/L)                              21
C    CGWLK   = CONCENTRATION OF GROUNDWATER DISCHARGE TO LAKE FROM              22
C              AN ELEMENT (MG/L/CM)                                             23
C    CIMP    = CONCENTRATION OF DISCHARGE FROM IMPERVIOUS AREA (MG/L)           24
C    CLK     = CONCENTRATION OF LAKE WATER (MG/L)                               25
C    C0,C1,C2,C3,C4,C5 = ROUTING COEFFICIENTS                                   26
C    CP      = CONCENTRATION OF RAINWATER (MG/L)                                27
C    CRV     = CONCENTRATION OF GROUNDWATER DISCHARGE TO RIVER FROM             28
C              AN ELEMENT (MG/L/CM)                                             29
C    CSRO    = CONCENTRATION OF SURFACE RUNOFF (MG/L)                           30
C    DT      = STORAGE DELAY TIME OF A GROUNDWATER ELEMENT                      31
C    DTFLK   = STORAGE DELAY TIME FOR THE LAKE                                  32
C    ELENAM  = 7 CHARACTER IDENTIFIER FOR A GROUNDWATER ELEMENT                 33
C    GWOLK   = LAKE DISCHARGE TO GROUNDWATER (CM)                               34
C    GWOLKT  = TOTAL LAKE DISCHARGE TO GROUNDWATER (M3)                         35
C    I       = SUBAREA LOOP COUNTER                                             36
C    ICE     = THICKNESS OF ICE ON THE LAKE (CM)                                37
C    ICEF    = AMOUNT OF NEWLY FORMED ICE ON LAKE (CM)                          38
C    INFILT  = INFILTRATION (CM)                                                39
C    J       = SERIES ELEMENT LOOP COUNTER                                      40
C    K       = PARALLEL PART OF ELEMENT COUNTER                                 41
C    LKSTG   = PRESENT LAKE STAGE (M)                                           42
C    LKVOL   = VOLUME OF WATER IN LAKE (M3)                                     43
C    LSZM    = ACTUAL MOISTURE IN LOWER SOIL ZONE (CM)                          44
C    LSZMP   = STARTING MOISTURE IN LOWER SOIL ZONE (CM)                        45
C    LSZMAX  = MAXIMUM LOWER SOIL ZONE STORAGE (CM)                             46
C    N       = RECORD LOOP COUNTER                                              47
C    NEGREC  = TEST TO SEE IF EVAPORATION IS ALLOWED FROM A                     48
C              GROUNDWATER ELEMENT (T,F)                                        49
C    NEGQGW  = TEST TO SEE IF GROUNDWATER RECHARGE FROM A SURFACE WATER         50
C              BODY IS ALLOWED TO A GROUNDWATER ELEMENT (T,F)                   51
C    NGWE    = NUMBER OF GROUNDWATER STORAGE ELEMENTS                           52
C    NOPP    = NUMBER OF PARALLEL PARTS OF AN ELEMENT                           53
C    NREC    = NUMBER OF RECORDS                                                54
C    NSUB    = NUMBER OF SUB-AREAS                                              55
C    P       = PRECIPITATION (CM)                                               56
C    PCTAR   = PERCENTAGE OF SUBAREA OF WHICH ELEMENT CONSISTS                  57
C    PCTELM  = PROPORTION OF OUTFLOW FROM AN ELEMENT ALLOCATED TO               58
C              OTHER ELEMENTS                                                   59
C    PCTIMP  = FRACTION OF SUBAREA WHICH IS IMPERVIOUS                          60
C    PE      = POTENTIAL EVAPORATION (CM)                                       61
C    PSW     = PRECIPITATION AS STORED AS SNOW IN WINTER (CM)                   62
C    QGN     = OUTFLOW FROM EACH GROUNDWATER STORAGE ELEMENT (CM)               63
C    QGNP    = PREVIOUS OUTFLOW FROM EACH GROUNDWATER STORAGE ELEMENT (CM)      64
C    QGWLK   = GROUNDWATER DISCHARGED TO LAKE  FROM AN ELEMENT (CM)             65
C    QGWLKT  = TOTAL GROUNDWATER DISCHARGE TO LAKE FROM AN ELEMENT (CM)         66
C    QGWRV   = GROUNDWATER DISCHARGE TO RIVER FROM AN ELEMENT (CM)              67
C    QRVT    = TOTAL GROUNDWATER DISCHARGE TO RIVER FROM AN ELEMENT (CM)        68
C    QRIVT   = TOTAL GROUNDWATER DISCHARGE TO RIVER (CM)                        69
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C     GGWT   = TOTAL GROUNDWATER OUTFLOW TO SURFACE (M3)                        70
C     GIMPT  = TOTAL FLOW FROM IMPERVIOUS AREAS (M3)                            71
C     GIMP   = QUANTITY OF FLOW FROM IMPERVIOUS AREA IN EACH BASIN (CM)         72
C     GINTR  = RUNOFF FROM WATERSHED BY INTERFLOW (CM)                          73
C     GINTRT = TOTAL INTERFLOW (M3)                                             74
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      LOGICAL*1 NEGREC(2,9),REPREC(2,9),NEGQGW(2,9),ELENAM(7)
      DATA SUB/'A','B','C','D','E','F','G','H','I','J'/,LX/0/
C
C
C  READ AND WRITE TITLE
      READ(5,114)TITLE
  114 FORMAT(20A4)
      WRITE(6,116)TITLE
  116 FORMAT(1H1,20A4//)
C
C  READ AND WRITE INITIAL CONSTANTS
      READ(5,100)NREC,NSUB,CP,TEMPP,ICE,SNOW
  100 FORMAT(2I5,F10.0,3F5.0)
      READ(5,115)LKSTG,SWOL,CLK,DTFLK,RTFLK,GWOLK
  115 FORMAT(6F10.0)
      WRITE(6,102)NREC,NSUB,SWOL,RTFLK,DTFLK,GWOLK
  102 FORMAT(1X,'INITIAL CONSTANTS:'//' NUMBER OF RECORDS:',I4/
     1       ' NUMBER OF SUBAREAS:',I4/' SURFACE WATER OUTFLOW LEVEL:',
     2       F8.3/' LAKE RECHARGE TIME:',F7.3/' LAKE STORAGE DELAY TIME:'
     3       ,F7.3/' LAKE DISCHARGE TO GROUNDWATER:',F7.3/)
C
C  READ AND WRITE SUBAREA DATA
      WRITE(6,106)
  106 FORMAT(//1X,'SUBAREA DATA:')
      DO 110 I=1,NSUB
      READ(5,101)ARSUB(I),RGHMAX(I),CIMP(I),CSRO(I),PCTIMP(I),
     1           USZMAX(I),LSZMAX(I),USZMP(I),LSZMP(I),NGWE(I)
  101 FORMAT(4F10.0,5F5.0,I5)
      WRITE(6,104)
  104 FORMAT(/' SUBAREA   AREA   USZMAX   LSZMAX  % IMP      CIMP'
     1       '     RGHMAX     CSRO       CP'/)
      WRITE(6,105)SUB(I),ARSUB(I),USZMAX(I),LSZMAX(I),PCTIMP(I),
     1            CIMP(I),RGHMAX(I),CSRO(I),CP
  105 FORMAT(1X,3X,A1,F10.2,F9.2,F9.2,F8.3,F10.1,F9.2,F9.1,F8.1)
      WRITE(6,112)
  112 FORMAT(//1X,9X,'ELEMENT  % AREA  REPREC  NEGREC  NEGQGW     DT ',
     1       '     RT     QGWP  RELMP  CGWSP  NOPP    % ELEM    TOELM')
C
      NGWEL=NGWE(I)
      DO 110 J=1,NGWEL
C
C  READ AND WRITE GROUNDWATER ELEMENT DATA
      READ(5,108)(ELENAM(L),L=1,7),REPREC(I,J),NEGREC(I,J),NEGQGW(I,J),
     1           DT(I,J),RT(I,J),QGWP(I,J),RELMP(I,J),PCTAR(I,J),
     2           CGW(I,J),NOPP(I,J)
  108 FORMAT(7A1,3L1,2F5.0,F10.0,I5)
      READ(5,109)(PCTELM(I,J,K),K=1,6),(TOELM(I,J,K),K=1,6)
  109 FORMAT(6F5.0,6I5)
      WRITE(6,111)J,(ELENAM(L),L=1,7),PCTAR(I,J),REPREC(I,J),NEGREC(I,J)
     1           ,NEGQGW(I,J),DT(I,J),RT(I,J),QGWP(I,J),RELMP(I,J),
     2           CGW(I,J),NOPP(I,J),PCTELM(I,J,1),TOELM(I,J,1)
  111 FORMAT(/7X,I2,1X,7A1,F7.3,L7,2L8,F9.3,F6.3,2F7.3,F7.1,I6,F9.4,I7)
      IF(NOPP(I,J).LE.1)GO TO 110
      NOP=NOPP(I,J)
      WRITE(6,113)(PCTELM(I,J,K),TOELM(I,J,K),K=2,NOP)
  113 FORMAT(1X,90X,F7.4,I7)
  110 CONTINUE
C
C READ PRECIPITATION AND EVAPORATION DATA
      READ(5,103)(P(N),N=1,NREC)
      READ(5,103)(PE(N),N=1,NREC)
      READ(5,103)(TEMP(N),N=1,NREC)
  103 FORMAT(12F5.0)
C
C  PRINT INITIAL VALUES
      WRITE(6,107)
  107 FORMAT(1H1,' TIME',13X,'EVAPORATION   SOIL-MOISTURE',11X,
     1       'LAKE-RECHARGE-SOURCES   RECHARGE   DISCHARGE-FROM-LAKE',
     2       '  LAKE   LAKE   ICE'/1X,'SUB TEMP.  PREC.   POT.   ACT.',
     3       ' UPPER LOWER DISCH INFILT  GW IMPER. RIVER S.R.O.  ',
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     4      'TO-LAKE     SURFACE  GRNDWATER  STAGE QUALITY THICK'/1X,
     5      7X,'C          CM       CM       CM       CM       CM       CM       CM       ',
     6      'CM       CM       CM       CM       M3       M3       M3',
     7      '          M        MG/L     CM'/)
      WRITE(6,117)(L,SUB(I),TEMPP,USZMP(I),LSZMP(I),LKSTG,CLK,ICE,
     1          I=1,NSUB)
  117 FORMAT(1X,I2,':',A1,F6.2,18X,2F6.2,69X,F8.3,F8.2,F6.2)
C
C  INITIALISE ROUTING COEFFECIENTS
C
      DO 40 I=1,NSUB
      ARSUB(I)=ARSUB(I)*10000.
      NGWEL=NGWE(I)
      DO 40 J=1,NGWEL
      C2(I,J)=EXP(-1.*RT(I,J)/DT(I,J))
      C0(I,J)=DT(I,J)/RT(I,J)*(1.-C2(I,J))
      C1(I,J)=C0(I,J)-C2(I,J)
      C0(I,J)=1.-C0(I,J)
      C4(I,J)=1./(EXP(RT(I,J)/DT(I,J))-1.)
      C3(I,J)=DT(I,J)/RT(I,J)-C4(I,J)
   40 CONTINUE
      PSW=SNOW/10.
C  CALCULATE VOLUME OF WATER IN LAKE AT SURFACE WATER OUTFLOW LEVEL
      SWOVOL=VOLLK(SWOL)
C
C  LOOP THROUGH RECORDS
C
      DO 500 N=1,NREC
C
C  LOOP THROUGH SUBAREAS
C
      DO 600 I=1,NSUB
C
C  CHECK FOR SUMMER OR WINTER CONDIONS
      IF(TEMPP(N).LE.0.)GO TO 27
      IF(TEMPP.LE.0.)P(N)=P(N)+PSW
C
C  ROUTE MOISTURE THROUGH SOIL ZONE
C
C  CALCULATE INFILTRATION
      GIMP(I)=PCTIMP(I)*P(N)
      INFILT(I)=P(N)-GIMP(I)-PE(N)
C  TEST TO SEE IF A SOIL ZONE IS PRESENT
      IF((USZMAX(I).EQ.0.).AND.(LSZMAX(I).EQ.0.))GO TO 10
      RUZ=INFILT(I)
      IF(RUZ-USZMAX(I)+USZMP(I))1,4,3
    3 RUZ=USZMAX(I)-USZMP(I)
      GO TO 4
    1 IF(RUZ.LT.0.0-USZMP(I))RUZ=0.0-USZMP(I)
    4 USZM(I)=USZMP(I)+RUZ
      RLZ=INFILT(I)-RUZ
      IF(RLZ)5,6,12
C  EVAPORATION OCCURS AT A REDUCED RATE IN LOWER SOIL ZONE
    5 RLZ=(LSZMP(I)/LSZMAX(I))*RLZ
    7 IF(RLZ-LSZMAX(I)+LSZMP(I))8,6,11
   11 RLZ=LSZMAX(I)-LSZMP(I)
      GO TO 6
    8 IF(RLZ.LT.0.0-LSZMP(I))RLZ=0.0-LSZMP(I)
    6 LSZM(I)=LSZMP(I)+RLZ
      GO TO 12
   10 LSZM(I)=0.
      USZM(I)=0.
      RLZ=0.
      RUZ=0.
C  CALCULATE RECHARGE TO THE GROUNDWATER ZONE AND SURFACE RUNOFF
   12 RGW(I)=INFILT(I)-RUZ-RLZ
      IF(RGW(I).GT.RGWMAX(I))GO TO 9
      INTR(I)=0.
      IF(RGW(I).LT.0.)RGW(I)=0.
      GO TO 2
```

```
    9 INTR(I)=RGW(I)-RGWMAX(I)                                          280
      RGW(I)=RGWMAX(I)                                                  281
C   AE DOES NOT INCLUDE EVAPORATION FROM GW ELEMENTS                    282
    2 AE(I)=INFILT(I)+PE(N)-RLZ-RUZ-RGW(I)-INTR(I)                      283
      LSZMP(I)=LSZM(I)                                                  284
      USZMP(I)=USZM(I)                                                  285
      P(N)=P(N)-PSW                                                     286
      PSW=0                                                             287
      GO TO 28                                                          288
C                                                                       289
C   DIVIDE G.W. RECHARGE AMONG G.W. ELEMENTS                            290
C                                                                       291
C   WINTER VALUES                                                       292
   27 INTR(I)=0.                                                        293
      QIMP(I)=0.                                                        294
      RGW(I)=0                                                          295
      INFILT(I)=0.                                                      296
      AE(I)=0                                                           297
      PSW=PSW+P(N)                                                      298
C                                                                       299
   28 NGWEL=NGWE(I)                                                     300
      DO 25 J=1,NGWEL                                                   301
      QGWLK(I,J)=0.                                                     302
      QGWRV(I,J)=0.                                                     303
   25 RELM(I,J)=0.                                                      304
      DO 600 J=1,NGWEL                                                  305
      IF(.NOT.REPREC(I,J))GO TO 21                                      306
C   FIND GROUNDWATER RECHARGE DIRECTLY FROM PRECIPITATION               307
      IF(.NOT.NEGREL(I,J))GO TO 24                                      308
      RELM(I,J)=RELM(I,J)+INFILT(I)*PCTAR(I,J)                          309
      GO TO 21                                                          310
C   FIND GROUNDWATER RECHARGE FROM SOIL ZONE                            311
   24 IF(RGW(I).LE.0.)GO TO 21                                          312
      RELM(I,J)=RELM(I,J)+RGW(I)*PCTAR(I,J)                             313
C   OUTFLOW FROM GROUNDWATER STORAGE ELEMENT                            314
   21 GGW(I,J)=C0(I,J)*RELM(I,J)+C1(I,J)*RELMP(I,J)+C2(I,J)*QGWP(I,J)   315
      S(I,J)=C3(I,J)*RELA(I,J)+C4(I,J)*QGW(I,J)                         316
      IF(.NOT.NEGGGW(I,J))GO TO 20                                      317
      IF(S(I,J).LT.0.)S(I,J)=0.                                         318
      GO TO 22                                                          319
   20 IF((QGW(I,J).GE.0.).AND.(S(I,J).GE.0.))GO TO 22                   320
      IF(SP(I,J).GT.0.)GO TO 29                                         321
      QGW(I,J)=0.                                                       322
      GO TO 22                                                          323
C   CALCULATE CORRECTED OUTFLOW FROM STORAGE ELEMENT                    324
   29 AX=(SP(I,J)/RELM(I,J))+(RT(I,J)/DT(I,J))                          325
      CS(I,J)=1.+ALOG(1.-AX)/AX                                         326
      QGW(I,J)=CS(I,J)*SP(I,J)                                          327
      S(I,J)=0.                                                         328
C   DIVIDE OUTFLOW FROM ELEMENT INTO PORTIONS AS DEFINED BY PARALLEL PAR 329
   22 NOP=NOPP(I,J)                                                     330
      DO 26 K=1,NOP                                                     331
      IF(TOELM(I,J,K).EQ.99)QGWLK(I,J)=PCTELM(I,J,K)*QGW(I,J)           332
      IF(TOELM(I,J,K).EQ.96)QGWRV(I,J)=PCTELM(I,J,K)*QGW(I,J)           333
      IF(TOELM(I,J,K).GE.90)GO TO 26                                    334
      RELM(I,TOELM(I,J,K))=RELM(I,TOELM(I,J,K))+PCTELM(I,J,K)*QGW(I,J)  335
   26 CONTINUE                                                          336
   23 QGWP(I,J)=QGW(I,J)                                                337
      RELMP(I,J)=RELM(I,J)                                              338
      SP(I,J)=S(I,J)                                                    339
C                                                                       340
  600 CONTINUE                                                          341
C                                                                       342
C TOTAL DISCHARGE AND WATER QUALITY CONTRIBUTIONS FROM SUBAREAS         343
C                                                                       344
      QGWT=0.                                                           345
      QINTRT=0.                                                         346
      QRIVT=0.                                                          347
      QIMPT=0.                                                          348
      RGWT=0.                                                           349
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```
      TCIMP=0.
      TCGWLK=0.
      TCRIV=0.
      TCSRO=0.
C  CALCULATE AREA OF THE LAKE
      ARLK=AREALK(LKSTG)*10000.
      DO 30 I=1,NSUB
      CGWLK(I)=0.
      GRVT(I)=0.
      QINTR(I)=0.
      QGWT(I)=0.
      CGWLK(I)=0
      QGWT=RGWT+QGW(I)
      QIMPT=QIMPT+QIMP(I)*ARSUB(I)
      TCIMP=TCIMP+QIMP(I)*ARSUB(I)*CIMP(I)
      NSAVE=NSVE(I)
      DO 35 J=1,NSAVE
      IF(.NOT.NEGEC(I,J))QINTR(I)=QINTR(I)+INTR(I)*PCTAR(I,J)
      CGWLK(I)=CGWLK(I)+CGW(I,J)
      GRVT(I)=GRVT(I)+GRNPV(I,J)
      CRV(I)=CRV(I)+GRNPV(I,J)*CGW(I,J)
   35 CGWLK(I)=CGWLK(I)+CGW(I,J)*CGW(I,J)
      GGWT=GGWT+GGWLK(I)*ARSUB(I)
      QINTRT=QINTRT+QINTR(I)*ARSUB(I)
      TCSRO=TCSRO+QINTRT*CSRO(I)
      GRVT=GRVT+GRVT(I)*ARSUB(I)
      TCRIV=TCRIV+CRV(I)*ARSUB(I)
      TCGWLK=TCGWLK+CGWLK(I)*ARSUB(I)
   30 CONTINUE
      TCP=P(N)*CP*ARLK
      GWOLKT=GWOLK*ARLK
      LKVOL=VOLLK(LKSTG)
      TCLK=CLK*LKVOL
C
C CALCULATION OF LAKE WATER QUALITY, ICE THICKNESS, RECHARGE TO LAKE
C
      IF(TEMP(N).GE.0.)GO TO 41
C
C  WINTER
      IF(TEMPP.LT.0.)GO TO 44
C  FIRST WINTER MONTH (ICE FORMS FOR ONLY LAST HALF OF MONTH)
      SNOW=P(N)*10./2.
      ICEF=SQRT(-255.*TEMP(N))
      ICE=ICEF
      RTLK=GGWT+GRIVT+(P(N)/2.-ICEF)*ARLK
      CLK=(TCGWLK+TCP/2.+TC(K,TCRIV)/(LKVOL+RTLK)
      CLK=(CLK*(LKVOL+RTLK))/(LKVOL+RTLK-(ICEF+PE(N)/2.)*ARLK)
      RTLK=RTLK-PE(N)/2.*ARLK-GWOLKT
      GO TO 46
C  WINTER MONTHS (EXCLUDING FIRST MONTH)
   44 SNOW=SNOW+P(N)/2.*10.
      TEMPS=(.17268E-3/SNOW*TEMP(N))/(.17268E-3/SNOW+.535E-2/ICE)
      ICEF=SQRT(-255.*TEMPS)
      ICE=ICE+ICEF
      RTLK=GGWT+GRIVT-ICEF*ARLK
      CLK=(TCGWLK+TCLK+TCRIV)/(LKVOL+RTLK)
      CLK=(CLK*(LKVOL+RTLK))/(LKVOL+RTLK-ICEF*ARLK)
      SNOW=SNOW+P(N)/2.*10.
      RTLK=RTLK-GWOLKT
      GO TO 46
C
C  SUMMER
   41 IF(TEMPP.GT.0.)GO TO 42
C  MELT ALL SNOW AND ICE BY THE END OF THE FIRST SUMMER MONTH
      RTLK=(P(N)+ICE+SNOW/10.)*ARLK+GGWT+QIMPT+QINTRT+GRIVT
      TCSNOW=SNOW/10.*CP*ARLK
      CLK=(TCIMP+TCSRO+TCGWLK+TCRIV+TCSNOW+TCLK+TCP)/(LKVOL+RTLK)
      CLK=CLK*(LKVOL+RTLK)/(LKVOL+RTLK-PE(N)*ARLK)
      RTLK=RTLK-PE(N)*ARLK-GWOLKT
      ICE=0.
```

```
      SNOW=0.
      GO TO 46
C  SUMMER MONTHS (EXCLUDING FIRST MONTH)
   42 RTLK=P(N)+ARLK+GSLT+GRVT+GIMPT+GINTRT
      CLK=(TCIMP+TCSRO+TCGWLK+TCRIV+TCP+TC(K)/(LKVOL+RTLK)
      CLK=(CLK*(LKVOL+RTLK))/(LKVOL+RTLK-PE(N)*ARLK)
      RTLK=RTLK-PE(N)*ARLK-GWOLKT
C
C  CALCULATE LAKE STAGE AND SURFACE WATER OUTFLOW
C
   46 LKVOL=LKVOL+RTLK
      SWO=0.
      SHI=0
C  CORRECT LAKE STAGE FOR SURFACE WATER OUTFLOW
      IF(LKVOL .LE. SHOVOL)GO TO 47
C  CALCULATE SURFACE WATER OUTFLOW
      SHI=LKVOL-SHOVOL
      SWO=OUTFLO(DTFLK,RTFLK,SHI)
      IF(LKVOL-SWO .LT. SHOVOL)SWO=LKVOL-SHOVOL
      LKVOL=LKVOL-SWO
   47 LKSTG=ELEVLK(LKVOL)
      TEMPP=TEMP(N)
C
C  OUTPUT
C
      IF(((N-NSUB)/25*25).EQ.(N-NSUB))WRITE(6,107)
C
      WRITE(6,207)N,SUB(1),TEMP(N),P(N),PE(N),AE(1),USZM(1),LSZM(1),
     1            RGW(1),INFILT(1),QGWLRT(1),QIMP(1),QRVT(1),QINTR(1),
     2            RTLK,SWO,GWOLKT,LKSTG,CLK,ICE
  207 FORMAT(/1X,I2,' ',A1,12F6.2,3E11.4,F8.3,F8.2,F6.2)
C
      IF(NSUB.LT.2)GO TO 500
C
      WRITE(6,208)(SUB(I),TEMP(N),P(N),PE(N),AE(I),USZM(I),LSZM(I),
     1            RGW(I),INFILT(I),QGWLRT(I),QIMP(I),QRVT(I),QINTR(I),
     2            I=2,NSUB)
  208 FORMAT(1X,'  ',A1,12F6.2)
C
  500 CONTINUE
      STOP
      END
      FUNCTION OUTFLO(DTFLK,RTFLK,LAKVOL)
C FUNCTION TO CALCULATE THE SURFACE WATER OUTFLOW FROM THE LAKE
      REAL LAKVOL
      OUTFLO=(LAKVOL/DTFLK)*EXP(-1.*RTFLK/DTFLK)
      RETURN
      END
      FUNCTION AREALK(LKSTG)
C  FUNCTION TO CALCULATE THE AREA OF THE LAKE AT A GIVEN LAKE STAGE
      REAL LKSTG
      AREALK=((LKSTG-552.26)/8.6)**2
      RETURN
      END
      FUNCTION ELEVLK(LKVOL)
C  FUNCTION TO CALCULATE THE STAGE OF A LAKE
      REAL LKVOL
      ELEVLK=557.82+.002193*SQRT(LKVOL)
      RETURN
      END
      FUNCTION VOLLK(LKSTG)
C FUNCTION TO CALCULATE THE VOLUME OF WATER IN THE LAKE
      REAL LKSTG
      VOLLK=((LKSTG-557.82)/.002193)**2
      RETURN
      END
```

APPENDIX III

SAMPLE INPUT CARD DECK

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LAKE-WATERSHED MODEL SENSITIVITY ANALYSIS
 96    1        10.   -1.   60.  120.
 577.750   577.750        180.          1.        0.5        4.000
    249.7          3.          10.          100.    13   5  10.0   0.   0.    5
SILT SZTFF   5.    1.   0.    0.  .160          400.     3
   30   50  .20                  99     5   98
SILT  TTF    5.    1.   0.    0.  .020          400.     3
   30   50  .20                  99     5   98
TILL SZTFF   1.    1.   0.    0.  .470          500.     3
   35   45  .20                  99     5   98
TILL  TTF    1.    1.   0.    0.  .350          500.     3
   35   45  .20                  99     5   98
DP TILLFF    7.    1. .005    0.    0.          600.     2
   .99  .40                      84    97
 0.23 1.7915.3212.73 4.98 3.53 3.63 1.91 3.45 5.89 0.91 2.29
 0.23 1.7615.2610.93 4.75 3.60 1.16 2.90 3.40 5.97 2.31 3.91
 3.31 2.7211.40 5.76 3.58 4.30 1.19 2.01 2.09 0.61 2.27 0.39
 3.34 2.7214.40 5.76 3.58 4.30 1.19 2.01 2.09 0.61 2.43 1.87
 2.46 2.32 9.40 5.18 4.08 7.68 4.75 6.12 4.37 3.24 2.02 2.73
 4.96 2.21 8.6017.43 4.08 6.10 1.04 4.06 1.31 6.64 1.02 1.71
 2.41 2.54 8.7813.31 1.74 6.44 1.05 0.21 4.34 1.42 1.83 2.01
 0.41 1.32 6.66 8.79 2.50 6.72 1.15 0.36 4.24 1.86 0.89 2.53
 1.7311.25 6.1019.34 2.46 6.97 1.50 0.37 1.73 2.00 2.00 2.00
 2.93 7.3419.3810.9415.4714.48 9.05 0.24 0.0   0.0   0.0   0.0
 5.62 6.1912.3110.0317.2713.32 9.68 1.21 0.0   0.0   0.0   0.0
 3.12 2.3213.9211.5916.3110.58 6.46 0.50 0.0   0.0   0.0   0.0
 1.9610.61 3.6812.1819.9013.20 7.89 2.44 0.0   0.0   0.0   0.0
 4.43 3.16 3.8014.8014.5212.62 9.33 3.14 0.0   0.0   0.0   0.0
 3.21 4.80 6.0619.8318.4212.26 6.93 2.26 0.0   0.0   0.0   0.0
 2.2310.04 8.7417.3017.0 9.8 9.9210.33 3.39 0.0   0.0   0.0   0.0
5.30 2.8517.9116.4916.1112.1210.42 0.00 0.00 0.00 0.00 0.00 0.00
 3.4 10.0 16.6 16.1 15.1  9.2  8.9 -9.5-20.3-22.2 -9.6 -7.6
 3.4 12.6 14.1 15.7 16.6  8.8  3.8 -6.4-18.6-20.5-17.7 -5.3
 1.1 11.8 14.2 14.0 16.3  5.5  1.8 -4.9-17.7-12.9-10.9 -2.1
 3.1 11.6 13.6 16.2 14.6  9.4  4.1-14.1-14.6-21.1-10.7-11.1
 4.0  8.1 14.8 14.9 12.4  6.3  6.5 -3.7 -6.0-13.6-14.7 -0.8
 0.7  9.6 13.2 17.8 12.5 10.9  3.6 -5.2-13.3-12.3 -9.3 -5.0
 6.5 11.3 12.8 16.9 16.7 12.4  3.5 -2.1-10.6-14.4 -0.9 -5.9
 6.6 11.5 14.8 14.4 12.4  9.5  5.2 -6.9-17.8 -5.0 -5.0 -5.0
```

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 BAPTISTE LAKE STUDY: EIGHT YEARS OF DATA
   96    1          10.    -1.   100.   120.
  576.800    577.780          200.          1.          0.5          4.000
    299.7          3.          10.        100.     13     5.  10.0    0.    0.    8
SILT SZTFF    1.    1.   0.    0. .150                  400.     3
     05   75  .20                 99                    6     98
SILT  TTF     1.    1.   0.    0. .020                  400.     3
     05   85  .10                 99                    6     98
TILL SZTFF    1.    1.   0.    0. .460                  500.     3
     05   75  .20                 99                    6     98
TILL  TTF     1.    1.   0.    0. .350                  500.     3
     05   75  .20                 99                    6     98
SAND SZTFF    1.    1.   0.    0. .020                  250.     3
     20   05  .75                 99                    6     98
DP TILLFFF    2.    1. .005   0.    0.                  600.     4
     60   03  .07  .30            99                    7      8     97
N CHAN.FFF    4.    1. .001 .001    0.                 1125.     2
     15   75                      99                   97
S CHAN.FFF    4.    1. .004 .004    0.                  775.     2
     15   75                      99                   97
 0.23 1.7915.3212.73 4.98 3.53 3.63 1.91 3.45 5.89 0.91 2.29
 0.49 1.6812.2510.66 6.15 4.20 1.90 2.60 3.48 5.77 2.31 1.61
 0.31 1.6211.4015.76 3.09 4.30 1.19 2.03 3.08 2.51 2.24 2.06
 0.74 2.13 9.40 5.18 3.09 4.20 4.45 0.12 4.83 2.51 1.43 3.97
 0.98 0.31 2.9017.42 5.98 7.20 4.02 4.07 1.91 0.64 1.04 2.97
 0.41 2.54 6.7813.31 5.74 5.34 4.65 0.61 4.34 1.42 1.85 2.01
 0.41 2.35 6.66 8.79 8.50 5.29 3.15 0.55 4.24 1.86 0.89 2.50
 1.7311.25 6.1012.34 5.46 2.97 1.50 0.97 1.73 2.00 2.00 2.00
 2.60 6.0212.6912.6510.80 2.80 1.77 0.0   0.0   0.0   0.0   0.0
 2.60 2.7310.3712.3011.69 5.51 2.17 0.0   0.0   0.0   0.0   0.0
 1.08 2.6211.4011.2311.84 3.93 1.32 0.0   0.0   0.0   0.0   0.0
 2.48 2.2510.7312.7710.56 6.00 2.40 0.0   0.0   0.0   0.0   0.0
 2.25 2.0111.6412.13 9.42 5.60 3.77 0.0   0.0   0.0   0.0   0.0
 0.97 2.2910.6014.01 9.35 6.90 2.25 0.0   0.0   0.0   0.0   0.0
 2.41 0.71 9.8912.9811.62 7.34 1.93 0.0   0.0   0.0   0.0   0.0
 4.77 9.1811.5911.56 9.16 6.04 2.99 0.0   0.0   0.0   0.0   0.0
 3.4 10.0 16.6 16.1 15.1 9.2  2.9 -9.5-20.3-22.2 -9.6 -7.6
 3.6 12.9 14.1 15.7 16.9 8.8  3.8 -6.4-18.6-20.5-17.7 -5.3
 3.1 11.8 14.2 14.0 16.3 5.5  1.8 -4.9-17.7-12.9-10.9 -2.1
 3.1 11.6 13.6 16.2 14.6 9.4  4.1-14.1-14.6-21.1-10.7-11.1
 4.0  8.1 14.8 14.9 12.4 8.3  6.5 -3.7 -6.0-13.6-14.7 -8.8
 0.7  9.6 13.2 17.6 12.5 10.9 3.6 -5.2-13.3-12.3 -9.3 -5.0
 6.5 11.3 12.8 16.9 16.7 12.4 3.5 -2.1-10.6-14.4 -0.9 -3.9
 6.6 11.5 14.8 14.4 12.4  9.5 5.2 -6.9-17.8 -5.0 -5.0 -5.0
```

APPENDIX IV

SAMPLE OUTPUT LISTING

BAPTISTE LAKE STUDY: EIGHT YEARS OF DATA

INITIAL CONSTANTS:

NUMBER OF RECORDS: 96
NUMBER OF SUBAREAS: 1
SURFACE WATER OUTFLOW LEVEL: 577.780
LAKE RECHARGE TIME: 0.500
LAKE STORAGE DELAY TIME: 1.000
LAKE DISCHARGE TO GROUNDWATER: 4.000

SUBAREA DATA:

SUBAREA	AREA	USZMAX	LSZMAX	% IMP	CIMP	RGWMAX	CSRO	CP
A	299.70	5.00	10.00	0.130	10.0	3.00	100.0	10.0

	ELEMENT	% AREA	REPREC	NEGREC	NEGQGW	DT	RT	QGWP	RELMP	CGWSF	NOPP	% ELEM	TOELM
1	SILT SZ	0.150	T	F	F	1.000	1.000	0.0	0.0	400.0	3	0.0500 0.7500 0.2000	99 6 98
2	SILT	0.020	T	T	F	1.000	1.000	0.0	0.0	400.0	3	0.0500 0.8500 0.1000	99 6 98
3	TILL SZ	0.460	T	F	F	1.000	1.000	0.0	0.0	500.0	3	0.0500 0.7500 0.2000	99 6 98
4	TILL	0.350	T	T	F	1.000	1.000	0.0	0.0	500.0	3	0.0500 0.7500 0.2000	99 6 98
5	SAND SZ	0.020	T	F	F	1.000	1.000	0.0	0.0	250.0	3	0.2000 0.0500 0.7500	99 6 98
6	DP TILL	0.0	F	F	F	7.000	1.000	0.005	0.0	600.0	4	0.6000 0.0300 0.0700 0.3000	99 7 8 97
7	N CHAN.	0.0	F	F	F	4.000	1.000	0.001	0.001	1125.0	2	0.1500 0.7500	99 97
8	S CHAN.	0.0	F	F	F	4.000	1.000	0.004	0.004	775.0	2	0.1500 0.7500	99 97

TIME SUB	TEMP. C	PREC. CM	EVAPORATION POT. CM	EVAPORATION ACT. CM	SOIL-MOISTURE UPPER CM	SOIL-MOISTURE LOWER CM	SOIL-MOISTURE DISCH CM	INFILT CM	LAKE-RECHARGE-SOURCES GW CM	LAKE-RECHARGE-SOURCES IMPER. CM	LAKE-RECHARGE-SOURCES RIVER CM	LAKE-RECHARGE-SOURCES S.R.O. CM	RECHARGE TO-LAKE M3	DISCHARGE-FROM-LAKE SURFACE M3	DISCHARGE-FROM-LAKE GRNDWATER M3	LAKE STAGE M	LAKE QUALITY MG/L	ICE THICK CM
0:A	-1.00				0.0	0.0										576.800	200.00	100.00
1:A	3.40	0.23	2.60	2.60	5.00	3.04	0.0	8.04	0.09	1.59	0.21	0.0	0.1428E+08	0.3848E+07	0.3257E+06	578.078	173.21	0.0
2:A	10.00	1.79	8.02	7.00	0.0	2.60	0.0	-6.46	0.10	0.23	0.10	0.0	0.3764E+06	0.1742E+07	0.3605E+06	577.916	175.60	0.0
3:A	16.60	15.32	12.69	12.69	0.64	2.60	0.0	0.64	0.08	1.99	0.0	0.0	0.6099E+07	0.4384E+07	0.3560E+06	578.120	165.56	0.0
4:A	16.10	12.73	12.65	11.96	0.0	2.35	0.0	-1.57	0.07	1.65	0.0	0.0	0.4825E+07	0.4651E+07	0.3617E+06	578.140	158.24	0.0
5:A	15.10	4.98	10.80	5.85	0.0	0.83	0.0	-6.47	0.06	0.65	0.0	0.0	0.1242E+07	0.2583E+07	0.3622E+06	577.981	156.94	0.0
6:A	9.20	3.53	5.80	3.30	0.0	0.60	0.0	-2.73	0.06	0.46	0.0	0.0	0.9808E+06	0.1610E+07	0.3578E+06	577.905	155.86	0.0
7:A	2.90	3.63	1.77	1.77	1.39	0.60	0.0	1.39	0.05	0.47	0.0	0.0	0.1369E+07	0.1463E+07	0.3557E+06	577.894	153.95	0.0
8:A	-9.50	1.91	0.0	0.0	1.39	0.60	0.0	0.0	0.05	0.0	0.03	0.0	-0.4406E+07	0.0	0.3554E+06	577.359	172.94	49.22
9:A	-20.30	3.45	0.0	0.0	1.39	0.60	0.0	0.0	0.05	0.0	0.01	0.0	-0.1804E+07	0.0	0.3407E+06	577.135	181.30	68.43
10:A	-22.20	5.89	0.0	0.0	1.39	0.60	0.0	0.0	0.04	0.0	0.00	0.0	-0.1410E+07	0.0	0.3347E+06	576.959	187.91	82.94
11:A	-9.60	0.91	0.0	0.0	1.39	0.60	0.0	0.0	0.04	0.0	0.00	0.0	-0.9321E+06	0.0	0.3299E+06	576.841	192.16	91.65
12:A	-7.60	2.29	0.0	0.0	1.39	0.60	0.0	0.0	0.03	0.0	0.00	0.0	-0.8486E+06	0.0	0.3268E+06	576.734	195.94	99.25
13:A	3.40	2.49	2.60	2.60	5.00	9.13	0.0	12.14	0.16	2.20	0.32	0.0	0.1685E+08	0.5089E+07	0.3239E+06	578.174	168.20	0.0
14:A	12.60	1.68	9.75	9.46	0.0	6.13	0.0	-8.29	0.19	0.22	0.16	0.0	0.5975E+06	0.2365E+07	0.3632E+06	577.964	172.88	0.0
15:A	14.10	12.75	10.97	10.97	0.12	6.13	0.0	0.12	0.15	1.66	0.0	0.0	0.5218E+07	0.4095E+07	0.3573E+06	578.097	165.86	0.0
16:A	15.70	10.69	12.30	11.19	0.0	4.36	0.0	-3.00	0.13	1.39	0.0	0.0	0.4049E+07	0.4067E+07	0.3610E+06	578.095	160.92	0.0
17:A	16.60	6.15	11.69	8.12	0.0	1.60	0.0	-6.34	0.11	0.80	0.0	0.0	0.1875E+07	0.2737E+07	0.3610E+06	577.993	159.50	0.0
18:A	8.80	1.60	5.51	2.05	0.0	0.94	0.0	-4.12	0.10	0.21	0.0	0.0	0.2110E+06	0.1204E+07	0.3581E+06	577.874	160.64	0.0
19:A	3.80	1.19	2.17	1.14	0.0	0.83	0.0	-1.13	0.09	0.15	0.0	0.0	0.2792E+06	0.6424E+06	0.3548E+06	577.830	161.35	0.0
20:A	-6.40	2.90	0.0	0.0	0.0	0.83	0.0	0.0	0.07	0.0	0.0	0.0	-0.3573E+07	0.0	0.3536E+06	577.396	177.48	40.40
21:A	-18.60	3.48	0.0	0.0	0.0	0.83	0.0	0.0	0.06	0.0	0.0	0.0	-0.1463E+07	0.0	0.3417E+06	577.215	184.61	55.81
22:A	-20.50	2.77	0.0	0.0	0.0	0.83	0.0	0.0	0.06	0.0	0.0	0.0	-0.1312E+07	0.0	0.3368E+06	577.052	191.11	69.40
23:A	-17.70	5.31	0.0	0.0	0.0	0.83	0.0	0.0	0.05	0.0	0.0	0.0	-0.1103E+07	0.0	0.3324E+06	576.913	196.59	80.43
24:A	-5.30	3.61	0.0	0.0	0.0	0.83	0.0	0.0	0.04	0.0	0.0	0.0	-0.6488E+06	0.0	0.3287E+06	576.831	199.64	85.88

TIME SUB	TEMP. C	PREC. CM	EVAPORATION POT. CM	EVAPORATION ACT. CM	SOIL-MOISTURE UPPER CM	SOIL-MOISTURE LOWER CM	SOIL-MOISTURE DISCH CM	INFILT CM	LAKE-RECHARGE-SOURCES CH IMPER. CM	LAKE-RECHARGE-SOURCES RIVER CM	LAKE-RECHARGE-SOURCES S.R.O. CM	RECHARGE TO-LAKE M3	DISCHARGE-FROM-LAKE SURFACE M3	DISCHARGE-FROM-LAKE GRNDWATER M3	LAKE STAGE M	LAKE QUALITY MG/L	ICE THICK CM
25:A	1.10	2.31	1.08	1.08	5.00	10.00	2.48	16.65	0.27	2.65	0.57	0.0	0.1858E+08	0.6608E+07	0.3265E+06	578.290	173.92	0.0
26:A	11.80	2.72	9.63	9.63	0.0	7.74	0.0	-7.26	0.36	0.35	0.43	0.0	0.2429E+07	0.4072E+07	0.3664E+06	578.096	182.39	0.0
27:A	14.20	11.40	11.40	11.06	0.0	6.59	0.0	-1.48	0.30	1.48	0.05	0.0	0.5143E+07	0.4721E+07	0.3610E+06	578.146	178.68	0.0
28:A	14.00	5.76	11.53	9.31	0.0	2.29	0.0	-6.52	0.27	0.75	0.02	0.0	0.2217E+07	0.3202E+07	0.3624E+06	578.029	179.53	0.0
29:A	16.30	3.58	11.84	5.12	0.0	0.29	0.0	-8.73	0.23	0.47	0.01	0.0	0.1016E+07	0.1875E+07	0.3591E+06	577.926	181.89	0.0
30:A	5.50	3.30	3.93	2.90	0.0	0.26	0.0	-1.06	0.20	0.43	0.00	0.0	0.1493E+07	0.1643E+07	0.3563E+06	577.908	182.51	0.0
31:A	1.80	1.19	1.32	1.04	0.0	0.25	0.0	-0.28	0.18	0.15	0.00	0.0	0.6317E+06	0.1029E+07	0.3558E+06	577.860	184.28	0.0
32:A	-4.90	2.03	0.0	0.0	0.0	0.25	0.0	0.0	0.15	0.0	0.00	0.0	-0.2932E+07	0.0	0.3544E+06	577.505	201.45	35.35
33:A	-17.70	2.08	0.0	0.0	0.0	0.25	0.0	0.0	0.13	0.0	0.00	0.0	-0.1440E+07	0.0	0.3447E+06	577.328	211.30	52.74
34:A	-12.90	0.51	0.0	0.0	0.0	0.25	0.0	0.0	0.12	0.0	0.00	0.0	-0.1199E+07	0.0	0.3399E+06	577.180	219.74	66.98
35:A	-10.90	2.77	0.0	0.0	0.0	0.25	0.0	0.0	0.10	0.0	0.00	0.0	-0.1050E+07	0.0	0.3359E+06	577.049	227.17	79.11
36:A	-2.10	0.36	0.0	0.0	0.0	0.25	0.0	0.0	0.09	0.0	0.00	0.0	-0.4884E+06	0.0	0.3323E+06	576.987	231.00	84.17
37:A	3.10	3.12	2.48	2.48	5.00	2.23	0.0	6.98	0.15	1.41	0.18	0.0	0.1249E+08	0.3661E+07	0.3307E+06	578.064	204.42	0.0
38:A	11.60	8.33	9.25	9.25	3.00	2.23	0.0	-2.00	0.18	1.08	0.15	0.0	0.3789E+07	0.3738E+07	0.3601E+06	578.070	201.39	0.0
39:A	13.60	9.40	10.73	10.73	0.45	2.23	0.0	-2.55	0.15	1.22	0.00	0.0	0.3631E+07	0.3672E+07	0.3603E+06	578.065	195.93	0.0
40:A	16.20	5.18	12.77	6.70	0.0	0.49	0.0	-8.26	0.13	0.67	0.00	0.0	0.1360E+07	0.2270E+07	0.3601E+06	577.957	195.03	0.0
41:A	14.60	7.09	10.56	6.38	0.0	0.27	0.0	-4.39	0.11	0.92	0.00	0.0	0.2431E+07	0.2367E+07	0.3571E+06	577.964	191.52	0.0
42:A	9.40	7.26	6.00	6.00	0.32	0.27	0.0	0.32	0.10	0.94	0.00	0.0	0.2875E+07	0.2675E+07	0.3573E+06	577.988	186.88	0.0
43:A	4.10	4.75	2.40	2.40	2.05	0.27	0.0	1.73	0.11	0.62	0.05	0.0	0.2177E+07	0.2372E+07	0.3580E+06	577.964	184.76	0.0
44:A	-14.10	6.12	0.0	0.0	2.05	0.27	0.0	0.0	0.11	0.0	0.05	0.0	-0.4954E+07	0.0	0.3573E+06	577.364	213.19	59.96
45:A	-14.80	4.83	0.0	0.0	2.05	0.27	0.0	0.0	0.10	0.0	0.02	0.0	-0.1075E+07	0.0	0.3408E+06	577.231	220.90	72.78
46:A	-21.10	5.61	0.0	0.0	2.05	0.27	0.0	0.0	0.09	0.0	0.01	0.0	-0.1074E+07	0.0	0.3372E+06	577.097	228.21	84.92
47:A	-10.70	3.43	0.0	0.0	2.05	0.27	0.0	0.0	0.08	0.0	0.00	0.0	-0.7477E+06	0.0	0.3336E+06	577.004	233.32	92.76
48:A	-11.10	3.87	0.0	0.0	2.05	0.27	0.0	0.0	0.07	0.0	0.00	0.0	-0.7471E+06	0.0	0.3311E+06	576.910	238.18	100.27
49:A	4.00	4.98	3.25	3.25	5.00	10.00	3.00	21.84	0.36	3.75	0.73	3.88	0.3589E+08	0.1749E+08	0.3286E+06	579.103	187.45	0.0

TIME SUB	TEMP. C	PREC. CM	EVAPORATION POT. CM	EVAPORATION ACT. CM	SOIL-MOISTURE UPPER CM	SOIL-MOISTURE LOWER CM	SOIL-MOISTURE DISCH CM	INFILT CM	LAKE-RECHARGE-SOURCES GW CM	LAKE-RECHARGE-SOURCES IMPER. CM	LAKE-RECHARGE-SOURCES RIVER CM	LAKE-RECHARGE-SOURCES S.R.O. CM	RECHARGE TO-LAKE M3	DISCHARGE-FROM-LAKE SURFACE M3	DISCHARGE-FROM-LAKE GRNDWATER M3	LAKE STAGE M	LAKE QUALITY MG/L	ICE THICK CM
50:A	8.10	2.31	7.01	7.01	0.0	10.00	0.0	-5.00	0.53	0.30	0.66	0.0	0.3612E+07	0.9069E+07	0.3897E+06	578.477	198.80	0.0
51:A	14.80	2.90	11.84	11.84	0.0	0.68	0.0	-9.32	0.44	0.38	0.07	0.0	0.1458E+07	0.4452E+07	0.3717E+06	578.125	204.70	0.0
52:A	14.90	17.42	12.13	12.13	3.03	0.68	0.0	3.03	0.38	2.26	0.02	0.0	0.8120E+07	0.6677E+07	0.3618E+06	578.295	194.82	0.0
53:A	12.40	5.08	9.42	7.58	0.0	0.55	0.0	-5.00	0.34	0.66	0.01	0.0	0.2252E+07	0.3993E+07	0.3666E+06	578.090	196.35	0.0
54:A	8.30	6.10	5.60	5.32	0.0	0.53	0.0	-0.29	0.29	0.79	0.00	0.0	0.2947E+07	0.3358E+07	0.3608E+06	578.041	195.39	0.0
55:A	6.50	1.04	3.77	1.06	0.0	0.38	0.0	-2.87	0.25	0.14	0.00	0.0	0.5674E+06	0.1665E+07	0.3595E+06	577.910	198.76	0.0
56:A	-3.70	1.06	0.0	0.0	0.0	0.38	0.0	0.0	0.22	0.0	0.00	0.0	-0.2376E+07	0.0	0.3558E+06	577.623	215.80	30.72
57:A	-6.00	1.91	0.0	0.0	0.0	0.38	0.0	0.0	0.19	0.0	0.00	0.0	-0.7308E+06	0.0	0.3479E+06	577.534	223.81	41.76
58:A	-13.60	2.64	0.0	0.0	0.0	0.38	0.0	0.0	0.17	0.0	0.00	0.0	-0.9117E+06	0.0	0.3455E+06	577.422	232.29	54.13
59:A	-14.70	1.04	0.0	0.0	0.0	0.38	0.0	0.0	0.15	0.0	0.00	0.0	-0.9356E+06	0.0	0.3424E+06	577.307	240.51	66.15
60:A	-8.80	1.73	0.0	0.0	0.0	0.38	0.0	0.0	0.13	0.0	0.00	0.0	-0.7418E+06	0.0	0.3393E+06	577.215	247.14	75.37
61:A	0.70	2.41	6.97	6.97	2.42	0.38	0.0	2.42	0.14	1.40	0.06	0.0	0.1109E+08	0.3924E+07	0.3368E+06	578.084	219.99	0.0
62:A	9.60	2.54	7.99	4.75	0.0	0.25	0.0	-5.78	0.12	0.33	0.01	0.0	0.5315E+06	0.1866E+07	0.3607E+06	577.925	220.58	0.0
63:A	13.20	9.78	10.60	8.56	0.0	0.20	0.0	-2.09	0.10	1.27	0.00	0.0	0.3688E+07	0.2971E+07	0.3563E+06	578.011	213.11	0.0
64:A	17.80	13.31	14.01	11.63	0.0	0.15	0.0	-2.43	0.09	1.73	0.00	0.0	0.5031E+07	0.4220E+07	0.3586E+06	578.107	202.89	0.0
65:A	12.50	11.74	9.35	9.35	0.86	0.15	0.0	0.86	0.08	1.53	0.00	0.0	0.4660E+07	0.4486E+07	0.3613E+06	578.127	193.83	0.0
66:A	10.90	2.34	6.90	2.96	0.0	0.09	0.0	-4.86	0.07	0.30	0.00	0.0	0.3394E+06	0.1970E+07	0.3619E+06	577.933	193.81	0.0
67:A	3.60	1.65	2.25	1.44	0.0	0.08	0.0	-0.81	0.06	0.21	0.00	0.0	0.4078E+06	0.1022E+07	0.3565E+06	577.860	193.42	0.0
68:A	-5.20	0.61	0.0	0.0	0.0	0.08	0.0	0.0	0.05	0.0	0.00	0.0	-0.3402E+07	0.0	0.3544E+06	577.447	210.34	36.41
69:A	-13.30	4.34	0.0	0.0	0.0	0.08	0.0	0.0	0.04	0.0	0.00	0.0	-0.1412E+07	0.0	0.3431E+06	577.273	217.52	50.41
70:A	-12.30	1.42	0.0	0.0	0.0	0.08	0.0	0.0	0.04	0.0	0.00	0.0	-0.1143E+07	0.0	0.3384E+06	577.131	223.29	61.27
71:A	-9.30	1.85	0.0	0.0	0.0	0.08	0.0	0.0	0.03	0.0	0.00	0.0	-0.9980E+06	0.0	0.3346E+06	577.007	228.28	70.39
72:A	-5.00	2.01	0.0	0.0	0.0	0.08	0.0	0.0	0.03	0.0	0.00	0.0	-0.7712E+06	0.0	0.3312E+06	576.910	231.89	76.74
73:A	6.50	0.41	4.41	4.41	4.85	0.08	0.0	4.85	0.08	1.38	0.13	0.0	0.1123E+08	0.2524E+07	0.3286E+06	577.976	205.48	0.0
74:A	11.30	3.35	8.71	7.77	0.0	0.08	0.0	-5.80	0.08	0.44	0.04	0.0	0.8295E+06	0.1495E+07	0.3577E+06	577.896	205.16	0.0

TIME !SUB	TEMP. C	PREC. CM	EVAPORATION POT. CM	EVAPORATION ACT. CM	SOIL-MOISTURE UPPER CM	SOIL-MOISTURE LOWER CM	SOIL-MOISTURE DISCH CM	INFILT CM	LAKE-RECHARGE-SOURCES GW CM	LAKE-RECHARGE-SOURCES IMPER. CM	LAKE-RECHARGE-SOURCES RIVER CM	LAKE-RECHARGE-SOURCES S.R.O. CM	RECHARGE TO-LAKE M3	DISCHARGE-FROM-LAKE SURFACE M3	DISCHARGE-FROM-LAKE GRNDWATER M3	LAKE STAGE M	LAKE QUALITY MG/L	ICE THICK CM
75:A	12.80	6.86	9.89	6.00	0.0	0.05	0.0	-3.92	0.06	0.89	0.00	0.0	0.2240E+07	0.1946E+07	0.3555E+06	577.931	200.72	0.0
76:A	16.90	8.79	12.68	7.67	0.0	0.02	0.0	-5.03	0.06	1.14	0.00	0.0	0.2888E+07	0.2517E+07	0.3564E+06	577.976	194.91	0.0
77:A	16.70	9.50	11.62	8.27	0.0	0.02	0.0	-3.35	0.05	1.23	0.00	0.0	0.3299E+07	0.2990E+07	0.3576E+06	578.012	188.33	0.0
78:A	12.40	2.72	7.34	2.37	0.0	0.01	0.0	-4.97	0.04	0.35	0.00	0.0	0.4128E+06	0.1426E+07	0.3587E+06	577.891	187.68	0.0
79:A	3.50	3.15	1.93	1.93	0.81	0.01	0.0	0.81	0.04	0.41	0.00	0.0	0.1090E+07	0.1222E+07	0.3553E+06	577.875	185.46	0.0
80:A	-2.10	0.56	0.0	0.0	0.81	0.01	0.0	0.0	0.04	0.0	0.02	0.0	-0.2222E+07	0.0	0.3549E+06	577.607	195.73	23.14
81:A	-10.60	4.24	0.0	0.0	0.81	0.01	0.0	0.0	0.03	0.0	0.01	0.0	-0.1113E+07	0.0	0.3475E+06	577.471	200.67	33.34
82:A	-14.40	1.86	0.0	0.0	0.81	0.01	0.0	0.0	0.03	0.0	0.00	0.0	-0.1065E+07	0.0	0.3438E+06	577.340	205.33	42.86
83:A	-0.90	0.89	0.0	0.0	0.81	0.01	0.0	0.0	0.03	0.0	0.00	0.0	-0.4633E+06	0.0	0.3402E+06	577.283	206.82	45.27
84:A	-3.90	2.53	0.0	0.0	0.81	0.01	0.0	0.0	0.02	0.0	0.00	0.0	-0.6595E+06	0.0	0.3386E+06	577.201	209.25	49.89
85:A	6.60	1.73	4.77	4.77	5.00	1.32	0.0	5.50	0.08	1.54	0.15	0.0	0.9709E+07	0.3017E+07	0.3364E+06	578.014	190.02	0.0
86:A	11.50	11.25	9.18	9.18	5.00	1.93	0.0	0.61	0.13	1.46	0.17	0.0	0.5130E+07	0.4297E+07	0.3587E+06	578.113	184.44	0.0
87:A	14.80	6.10	11.59	10.55	0.0	1.68	0.0	-6.28	0.11	0.79	0.01	0.0	0.1884E+07	0.2834E+07	0.3615E+06	578.000	182.51	0.0
88:A	14.40	19.34	11.56	11.56	5.00	1.95	0.0	5.27	0.10	2.51	0.02	0.0	0.8259E+07	0.6124E+07	0.3583E+06	578.253	169.03	0.0
89:A	12.40	5.46	9.16	9.16	0.59	1.95	0.0	-4.41	0.10	0.71	0.03	0.0	0.1837E+07	0.3524E+07	0.3654E+06	578.053	167.80	0.0
90:A	9.50	5.97	6.04	5.83	0.0	1.90	0.0	-0.85	0.09	0.78	0.00	0.0	0.2221E+07	0.2733E+07	0.3598E+06	577.992	164.99	0.0
91:A	5.20	1.50	2.99	1.62	0.0	1.58	0.0	-1.69	0.08	0.19	0.00	0.0	0.3203E+06	0.1269E+07	0.3581E+06	577.879	165.38	0.0
92:A	-6.90	0.97	0.0	0.0	0.0	1.58	0.0	0.0	0.07	0.0	0.00	0.0	-0.3836E+07	0.0	0.3550E+06	577.414	182.54	41.95
93:A	-17.80	1.73	0.0	0.0	0.0	1.58	0.0	0.0	0.06	0.0	0.00	0.0	-0.2135E+07	0.0	0.3422E+06	577.150	192.93	64.91
94:A	-5.00	2.00	0.0	0.0	0.0	1.58	0.0	0.0	0.05	0.0	0.00	0.0	-0.1021E+07	0.0	0.3350E+06	577.022	197.98	74.88
95:A	-5.00	2.00	0.0	0.0	0.0	1.58	0.0	0.0	0.04	0.0	0.00	0.0	-0.9051E+06	0.0	0.3316E+06	576.908	202.38	83.36
96:A	-5.00	2.00	0.0	0.0	0.0	1.58	0.0	0.0	0.04	0.0	0.00	0.0	-0.8436E+06	0.0	0.3286E+06	576.802	206.41	91.01

APPENDIX V

BAPTISTE LAKE HYDROLOGIC DATA

Baptiste Lake Surface Elevations

(all values are recorded on the last day of the month)
(units are meters above mean sea level)

	1972	1973	1974	1975	1976	1977	1978
Jan	-	-	-	-	-	-	-
Feb	-	-	-	-	-	-	-
Mar	-	-	-	-	-	-	-
Apr	?	?	578.867	578.026	577.962	?	578.059
May	578.068	577.809	578.181	577.822	577.831	?	578.062
Jun	577.989	578.169	577.904	577.943	577.843	578.017	578.067
Jul	577.883	578.035	578.367	578.297	577.819	578.257	578.107
Aug	577.782	577.968	578.148	578.343	577.858	578.053	578.139
Sep	577.727	577.937	578.023	578.224	577.861	578.099	578.765
Oct	577.709	577.916	577.919	577.977	577.843	578.081	578.271
Nov	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-

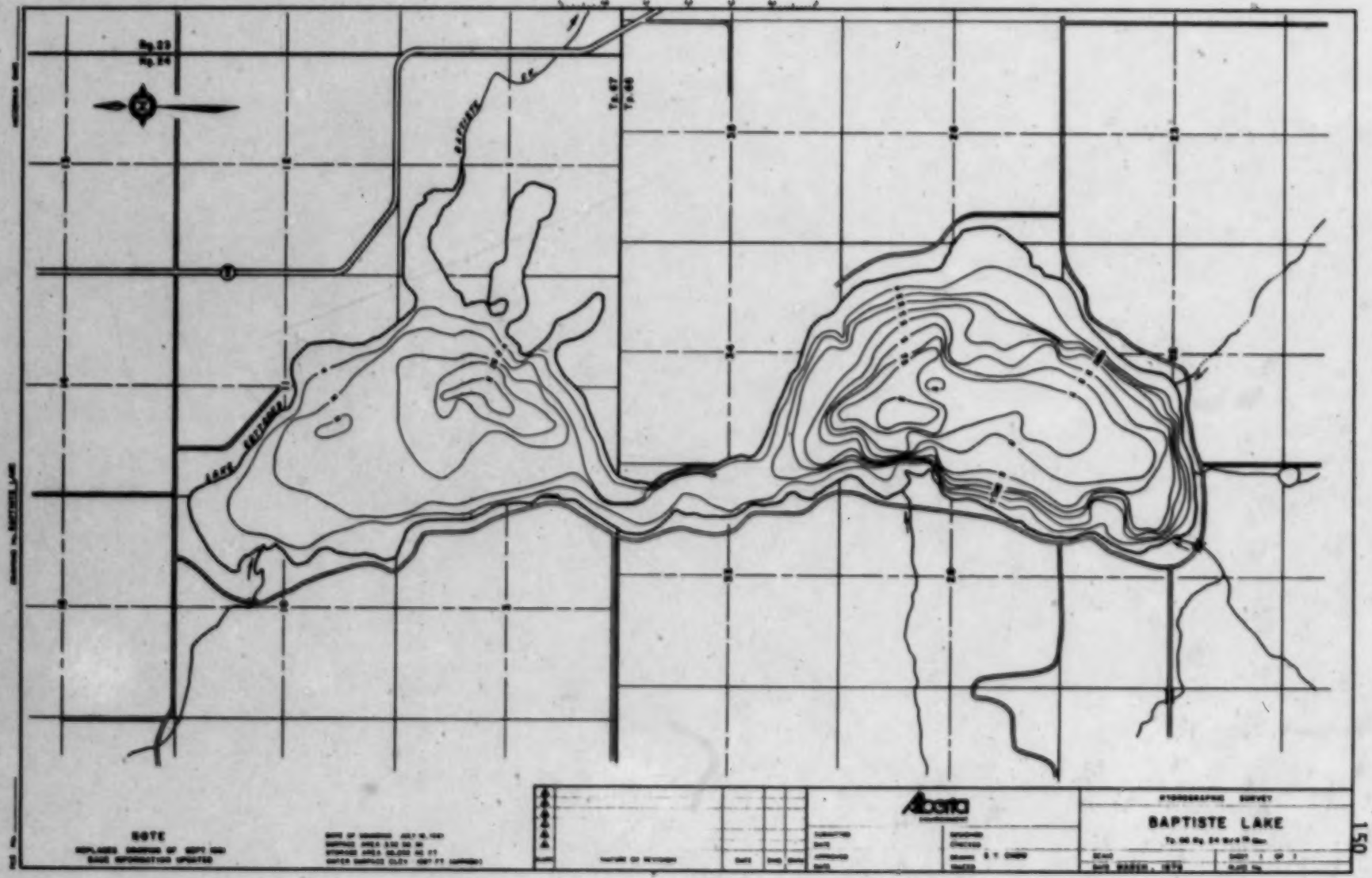
- : lake was frozen
? : lake level not recorded

* Recorded by the Water Survey of Canada

Ice Thicknesses on the Two Basins of Baptiste Lake

Baptiste South		Baptiste North	
Nov 20, 1976	frozen over	Nov 10, 1976	frozen over
Dec 15, 1976	20-25 cm	Dec 1, 1976	23 cm
Jan 5, 1977	36-46 cm	Dec 15, 1976	20-26 cm
Feb 16, 1977	49 cm	Jan 5, 1977	31-33 cm
Mar 9, 1977	51 cm	Jan 19, 1977	31 cm
Mar 23, 1977	61 cm	Feb 2, 1977	38-46 cm
Apr 25, 1977	ice out	Feb 16, 1977	51-54 cm
		Mar 9, 1977	51 cm
		Mar 23, 1977	56-61 cm
		Apr 25, 1977	ice out

*ice thickness supplied by D. Beliveau, Water Quality Control Branch, Alberta Environment.


Alberta
BAPTISTE LAKE
NOTE

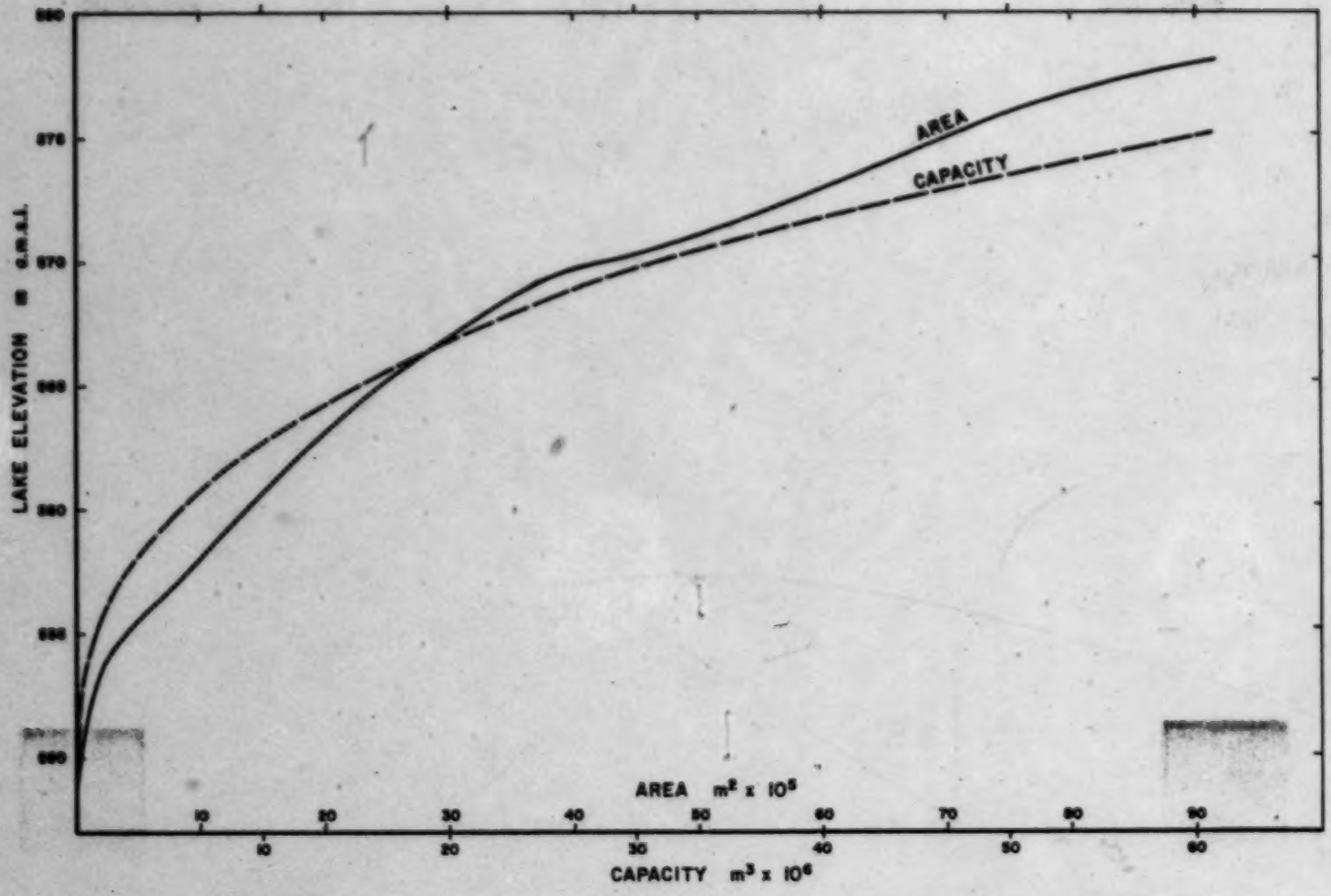


FIGURE 30. BAPTISTE LAKE AREA - CAPACITY CURVES

APPENDIX VI

BAPTISTE LAKE HYDROCHEMICAL DATA

	Mar 16	Mar 30	Apr 28	May 5	May 17	May 19	May 26	June 1	June 8	June 15	June 22	June 28	July 7	July 15	July 20	July 28	Aug 2	Aug 11
pH	7.8	8.0	8.4	8.5	8.4	8.2	9.0	8.5	8.7	8.9	9.0	8.5	8.9	8.2	8.6	8.0	8.3	8.8
CONDUCTIVITY $\mu S\,cm^{-1}$	320	310	260	285	300	280	230	310	295	300	300	330	285	240	220	300	305	235
CALCIUM $mg\,l^{-1}$	47	38	37	40	36	42	25	31	34	34	40	40	33	16	10	21	26	33
MAGNESIUM $mg\,l^{-1}$	10	11	11	10	1	9	12	11	11	13	11	9	12	15	15	16	15	9
T-HARDNESS $mg\,l^{-1}$	158	138	137	140	133	139	110	122	129	137	145	137	131	102	87	129	128	120
SODIUM $mg\,l^{-1}$	21	20	21	17	19	19	19	21	19	20	19	21	20	16	19	21	20	15
POTASSIUM $mg\,l^{-1}$	3.6	3.4	3.9	3.6	3.8	3.9	4.3	3.6	3.9	3.9	3.9	3.6	3.9	3.6	4.0	3.0	3.4	3.1
IRON $mg\,l^{-1}$	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*	0.10*	0.1	0.1	0.1*	0.1	0.1*	0.1*	0.1*	0.25	0.1*	0.1*	0.06
SILICA $mg\,l^{-1}$																		
CHLORIDE $mg\,l^{-1}$	3	4	2	1	2	1*	2	1*	1*	1*	1*	1*	1*	1*	1*	4	2	3
SULPHATE $mg\,l^{-1}$	43	20	22	10*	10*	16	19	10*	10*	25	23	16	10*	14	10*	10*	30	10*
FLUORIDE $mg\,l^{-1}$	0.21	0.15	0.21	0.20	0.13	0.16	0.07	0.22	0.14	0.15	0.14	0.11	0.07	0.05	0.05*	0.13	0.05*	0.09
BICARBONATE $mg\,l^{-1}$	224	211	194	191	202	217	123	208	199	185	191	213	171	192	132	200	215	175
T-ALKALINITY $mg\,l^{-1}$	184	173	161	162	168	178	119	173	174	167	174	177	161	158	114	164	176	154
TDS $mg\,l^{-1}$	238	201	193	179	182	197	151	182	189	196	203	197	176	160	134	176	202	170
COD $mg\,l^{-1}$	62.6	49.0			52.0	47.0		47.4		51.6	46.0		102.6	38.0		55.7	58.1	
NH_3-N $mg\,l^{-1}$	0.20*	0.20*	0.20*	0.20*	0.20*	0.20*	0.05*	0.20*	0.20*	0.20*	0.22	0.31	0.20*	0.20*	0.05*	0.18	0.93	0.05*
PHOSPHATE-T $mg\,l^{-1}$	.16	.13	.13	.10	.02	.08	.07	0.02	.06	.11	.04	0.08	.11	.07	.07	0.04	.38	0.09
TKN $mg\,l^{-1}$	0.90	0.80	1.10	1.60	1.39	1.12	0.76	1.32	1.65	1.49	1.34	1.30	0.68	1.70	1.12	1.04	1.23	0.98
O-PO_4 $mg\,l^{-1}$	0.145	0.150	0.019	0.006	0.14	0.014	0.019	0.007	0.010	0.004	0.019	0.015	0.011	0.016	0.007	0.010	0.022	0.019
NO_2-N+NO_3-N $mg\,l^{-1}$	0.494	0.369	0.020	0.005	0.015	0.011	0.026	0.026	0.029	0.033	0.028	0.058	0.039	0.023	0.003	0.049	0.050	0.002*
DISCHARGE $m^3\,day^{-1}$																		
TEMPERATURE °C							F							F	F	F		F

	Aug 17	Aug 24	Aug 30	Sept 8	Sept 15	Sept 21	Sept 27	Oct 5	Oct 13	Oct 20	Oct 27	Nov 3	Nov 10	Dec 15	Jan 5	Jan 19	Feb 2	Feb 16
pH	9.0	8.6	8.1	8.6	8.7	8.2	8.8	8.4	8.3	8.1	8.4	8.3	8.7	8.3	8.2	8.1	8.1	8.0
CONDUCTIVITY $\mu S\,cm^{-1}$	240	275	280	290	185	295	300	295	295	310	265	250	290	315	315	330	335	336
CALCIUM $mg\,l^{-1}$	23	24	25	45	26	30	28	31	33	33	31	21	31	29	35	36	37	44
MAGNESIUM $mg\,l^{-1}$	10	16	10	2	6	11	13	11	11	11	10	9	12	12	13	12	12	10
T HARDNESS $mg\,l^{-1}$	100	124	103	122	87	121	123	123	126	127	119	88	129	127	141	140	142	150
SODIUM $mg\,l^{-1}$	19	19	20	22	10	20	20	20	20	29	17	15	22	21	22	20	21	21
POTASSIUM $mg\,l^{-1}$	10.6	3.7	3.6	4.2	1.8	3.8	3.6	3.8	3.8	3.7	3.2	2.7	3.8	3.8	4.0	3.6	4.2	4.3
IRON $mg\,l^{-1}$	0.07	0.1*	0.1*	0.1*	0.05*	0.1*	0.1*	0.4	0.1*	0.10*	0.05*	0.05*	0.10	0.11	0.11	0.05	0.47	0.07
SILICA $mg\,l^{-1}$																		0.5*
CHLORIDE $mg\,l^{-1}$	1*	1	3	.3	2	2	1*	1	2	2	1*	3	2	3	1*	2	1*	2
SULPHATE $mg\,l^{-1}$	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*
FLUORIDE $mg\,l^{-1}$	0.13	0.10	0.10	0.12	0.08	0.11	0.10	0.08	0.11	0.13	0.08	0.11	0.09	0.13	0.18	0.11	0.11	0.12
BICARBONATE $mg\,l^{-1}$	163	160	185	166	202	197	179	202	202	217	188	167	176	212	218	224	209	208
T-ALKALINITY $mg\,l^{-1}$	139	142	152	146	168	162	159	168	166	178	159	146	157	174	179	184	171	171
TDS $mg\,l^{-1}$	168	149	162	174	179	174	171	179	178	196	169	143	164	173	192	194	190	193
COD $mg\,l^{-1}$		57.2	64.5	51.1	52.0	43.4	51.0	52.0	37.1	44.6	37.4		34.5	41.2	16.5	45.6		
NH_3-N $mg\,l^{-1}$	0.05	0.05*	0.05*	0.13	0.16	0.05*	0.07	0.16	0.12	0.30	0.31	0.07	0.33	0.35	0.11	0.81	0.05*	0.05*
PHOSPHATE-T $mg\,l^{-1}$	0.07	0.06	0.21	0.20*	0.08	0.10	0.07	0.08	0.09	0.13	0.13	0.17	0.08	0.06	0.07	0.11	0.17	0.08
TKN $mg\,l^{-1}$	1.11	1.34	2.14	1.37	1.15	1.38	1.33	1.15	1.14	1.12	1.12	0.96	1.01	1.78	1.53	1.44	1.66	1.36
O-PO_4 $mg\,l^{-1}$	0.010	0.024	0.085	0.048	0.028	0.038	0.032	0.028	0.065	0.029	0.032	0.026	0.053	0.062	0.034	0.037	0.018	0.035
NO_2-N+NO_3-N $mg\,l^{-1}$	0.002*	0.019	0.071	0.019	0.033	0.022	0.025	0.033	0.089	0.041	0.082	0.048	0.044	0.184	0.327	0.256	0.500	0.056
DISCHARGE $m^3\,day^{-1}$																		
TEMPERATURE °C	F				F						F	F	F					

South Basin of Baptiste Lake, sampled from top of lake, 1976-1977.
analyses supplied by Water Quality Control Branch, Alberta Environment

	Mar 9	Mar 23	Apr 27	May 11	May 18	May 25	May 31	June 8	June 22	July 6	July 13	July 19	July 27	Aug 3	Aug 10	Aug 17	Aug 24	Aug 31
pH	8.0	7.7	8.3	8.6	8.5	8.7	8.3	9.0	8.7	9.5	8.9	8.9	9.2	8.9	9.1			8.8
CONDUCTIVITY μS cm^{-1}	340	340	275	320	330	220	325	239	330	225	305	330	295	245	295			166
CALCIUM mg l^{-1}	39	39	37	38	35	14	38	18	37	14	38	36	28	31	31			10
MAGNESIUM mg l^{-1}	11	12	12	11	12	10	12	10	12	11	11	12	11	11	11			7
T-HARDNESS mg l^{-1}	142	148	141	141	136	75	144	88	141	80	142	137	115	123	123			56
SODIUM mg l^{-1}	22	20	20	20	21	19	20	20	20	19	21	21	20	20	20			12
POTASSIUM mg l^{-1}	4.2	4.0	3.8	3.8	4.0	3.7	3.7	3.8	3.7	3.7	3.7	4.2	3.7	3.6	3.8			2.3
IRON mg l^{-1}	0.07	0.12	0.05*	0.15	0.05*	0.05*	0.23	0.05*	0.07	0.05*	0.05*	0.05	0.05*	0.05*	0.05*			0.05*
SILICA mg l^{-1}	0.5*	0.5*	0.5*	0.5*	05*	0.5*	0.5*	0.5*	0.5*	0.8	0.9	1.4	1.2	1.3	1.2			2.2
CHLORIDE mg l^{-1}	1*	3	2	2	3	2	2	2	2	2	2	2	1*	2	2			2
SULPHATE mg l^{-1}	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*			10*
FLUORIDE mg l^{-1}	0.10	0.08	0.11	0.10	0.12	0.05*	0.12	0.07	0.09	0.05*	0.13	0.11	0.08	0.09	0.10			0.09
BICARBONATE mg l^{-1}	209	214	144	199	198	121	200	122	171	97	171	104	146	160	158			85
T-ALKALINITY mg l^{-1}	172	176	118	171	167	102	164	111	163	109	153	151	146	145	147			77
TDS mg l^{-1}	190	194	155	187	185	119	184	130	182	115	178	175	161	164	156			90
COD mg l^{-1}		49.0	34.2	37.1	31.3		46.1		53.0	34.1	53.4	56.1	56.0	53.1	58.7			30.1
NH_3-N mg l^{-1}	0.05*	0.18	0.12	0.62	0.20	0.05*	0.06	0.10	0.14	0.09	0.07	0.16	0.05*	0.14	0.08	0.06	0.05*	0.08
PHOSPHATE-T mg l^{-1}	0.07	0.15	0.10	0.08	0.10	0.05*	0.05*	0.06	0.05*	0.09	0.05*	0.05*	0.05*	0.05*	0.06	0.13	0.06	0.05*
TKN mg l^{-1}	1.37	2.01	0.88	1.77	1.87	0.64	1.47	1.72	1.50	0.99	1.80	1.98	2.14	2.27	1.72	2.20	1.12	0.92
O-PO_4 mg l^{-1}	0.059	0.013	0.01*	0.006	0.006	0.011	0.005	0.019	0.006	0.010	0.013	0.010	0.014	0.013	0.010	0.033	0.012	0.030
NO_3-N+NO_2-N mg l^{-1}	0.368	0.039	0.404	0.003	0.009	0.015	0.002*	0.027	0.003	0.008	0.003	0.004	0.004	0.009	0.002*	0.013	0.002*	0.038
DISCHARGE m^{3}sec^{-1}																		
TEMPERATURE °C			F			F		F		F							F	F

	Sept 8	Sept 11	Sept 21	Sept 28	Oct 5	Oct 12	Oct 17	Oct 26	Nov 2	Nov 8	Nov 16							
pH		8.2	8.3	8.2	8.1	7.6	8.4	7.6	8.1	7.8	7.7							
CONDUCTIVITY μS cm^{-1}		300	305	310	320	334	315	310	335	340	330							
CALCIUM mg l^{-1}		33	33	34	35	35	34	36	35	36	36							
MAGNESIUM mg l^{-1}		11	12	10	12	12	11	11	12	11	11							
T HARDNESS mg l^{-1}		127	131	128	135	137	129	137	136	135	137							
SODIUM mg l^{-1}		21	36	20	20	21	20	19	21	21	23							
POTASSIUM mg l^{-1}		3.8	3.8	3.6	3.7	3.8	3.7	3.6	3.8	3.8	4.0							
IRON mg l^{-1}		0.05*	0.05*	0.05*	0.29	0.12	0.05*	0.05*	0.05*	0.05*	0.05*							
SILICA mg l^{-1}		1.0	0.5*	0.5*	6.0	0.8	1.0	0.7	0.7	0.5*	0.8							
CHLORIDE mg l^{-1}		2		2	2	2	3	2	2	2	4							
SULPHATE mg l^{-1}		17	10*	10*	19	10*	10*	10*	10*	13	10*							
FLUORIDE mg l^{-1}		0.13	0.10	0.12	0.09	0.10	0.11	0.10	0.09	0.09	0.09							
BICARBONATE mg l^{-1}		179	183	180	192	191	18.3	187	186	187	187							
T-ALKALINITY mg l^{-1}		147	151	148	157	156	151	153	153	153	153							
TDS mg l^{-1}		176	211	168	187	178	172	174	175	181	181							
COD mg l^{-1}		46.4		60.0	70.0	42.0	45.5	33.3	44.2	39.4								
NH_3-N mg l^{-1}	0.39	0.22	0.09	0.05*	0.14	0.06	0.44	0.38	0.43	0.31	0.31							
PHOSPHATE-T mg l^{-1}	0.12	0.06	0.05*	0.07	0.05*	0.06	0.11	0.09*	0.11	0.12	0.11							
TKN mg l^{-1}	1.37	1.80	1.62	1.94	1.98	2.03	2.22	1.67	2.11	2.16	1.77							
O-PO_4 mg l^{-1}	0.097	0.034	0.033	0.010	0.016	0.056	0.080	0.035	0.029	0.041	0.027							
NO_3-N+NO_2-N mg l^{-1}	0.020	0.038	0.029	0.020	0.049	0.034	0.106	0.277	0.141	0.289	0.136							
DISCHARGE m^{3}sec^{-1}																		
TEMPERATURE °C	F																	

	Mar.16	Mar.30	Apr.28	May 5	May 17	May 19	May 26	June 1	June 8	June 15	June 22	June 28	July 7	July 15	July 20	July 28	Aug.2	Aug.11
pH	7.7	7.9	8.0	8.2	8.3	8.2	8.9	8.2	8.1	8.1	8.0	9.3	8.9	8.0	8.3	8.1	8.3	8.3
CONDUCTIVITY	320	320	270	290	300	290	235	300	300	310	310	310	195	245	250	325	325	285
CALCIUM	46	32	39	39	37	42	19	36	34	34	41	41	36	23	19	29	28	28
MAGNESIUM	10	10	10	9	10	9	12	11	11	13	11	9	10	13	15	16	16	11
T-HARDNESS	157	122	139	135	133	141	97	133	129	137	145	141	131	110	108	139	135	116
SODIUM	20	19	21	16	18	19	19	19	19	20	18	21	20	17	18	20	19	18
POTASSIUM	3.5	3.2	4.0	3.8	3.8	3.9	3.8	3.6	3.9	4.0	3.3	3.6	3.6	2.7	3.8	3.0	3.6	3.6
IRON	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*	0.10*	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*	0.17	0.1*	0.1*	0.06
SILICA																		
CHLORIDE	3	10	2	1	2	1*	1*	1*	1*	1*	1*	6	1*	1*	1*	2	1*	5
SULPHATE	40	10*	17	10*	10*	18	10*	10*	10*	10*	10*	19	10*	22	10*	23	25	10*
FLUORIDE	0.20	0.36	0.19	0.20	0.13	0.16	0.07	0.19	0.14	0.15	0.14	0.11	0.07	0.05*	0.05*	0.12	0.10	0.13
BICARBONATE	218	202	206	206	205	208	129	207	209	200	224	173	183	192	157	209	224	202
T-ALKALINITY	179	166	169	169	168	171	121	170	171	164	184	175	170	158	128	171	184	166
TDS	231	176	196	181	182	195	137	182	182	180	194	204	183	173	144	196	204	175
COD	45.1	75.0			54.0	38.0				40.9	37.9		51.7	26.5		49.0	50.0	
NH_3-N	0.20*	0.20*	0.20*	0.20*	0.20*	0.20*	0.05*	0.21	0.20*	0.20*	0.20*	0.20*	0.20*	0.18	0.05*	0.11	0.13	0.06
PHOSPHATE-T	0.13	0.10	0.10	0.10	0.02	0.08	0.05*	0.07	0.06	0.15	0.09	0.11	0.04	0.08	0.07	0.12	0.17	0.15
TKN	0.80	0.70	0.80	1.40	1.59	1.13	0.79	1.21	1.72	0.94	1.18	2.22	1.31	1.00	0.92	0.94	1.45	0.85
O-PO_4	0.139	0.045	0.041	0.022	0.014	0.017	0.016	0.025	0.030	0.032	0.036	0.016	0.009	0.191	0.015	0.105	0.087	0.078
NO_3-N+NO_2-N	0.520	0.217	0.051	0.109	0.015	0.028	0.067	0.094	0.097	0.233	0.222	0.031	0.046	0.242	0.020	0.208	0.122	0.073
DISCHARGE																		
TEMPERATURE °C																		
							F								F			F

	Aug.17	Aug.24	Aug.30	Sept.8	Sept.15	Sept.21	Sept.27	Oct.5	Oct.13	Oct.20	Oct.27	Nov.3	Nov.10	Dec.15	Jan.5	Jan.19	Feb.2	Feb.16
pH		8.8	8.6	8.0	8.1	8.2	8.1	8.3	8.3	8.1	8.6	8.5	8.8	8.3	8.1	8.0	7.9	8.0
CONDUCTIVITY		275	295	320	265	300	316	295	295	315	220	285	305	320	305	330	330	335
CALCIUM		23	27	52	31	31	30	32	34	33	30	18	33	35	33	36	37	41
MAGNESIUM		16	10	2	10	11	13	11	10	11	7	10	13	11	12	12	12	10
T HARDNESS		121	108	138	119	123	129	125	124	127	103	87	136	136	133	138	142	146
SODIUM		19	19	19	18	19	20	20	19	28	12	17	23	20	20	20	21	21
POTASSIUM		3.7	3.3	3.8	3.4	3.7	3.8	3.8	3.6	3.9	2.2	3.5	3.9	3.9	3.8	3.4	4.2	4.2
IRON		0.1*	0.1*	0.1*	0.05*	0.1*	0.1*	0.6	0.1*	0.10*	0.05*	0.05*	0.10	0.05*	0.08	0.11	0.16	0.07
SILICA																		0.8
CHLORIDE		1*	1*	1	1*	1*	1*	3	2	2	1*	1*	2	1	1*	1	1*	2
SULPHATE		10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*
FLUORIDE		0.09	0.10	0.10	0.08	0.12	0.10	0.09	0.11	0.11	0.08	0.09	0.11	0.09	0.12	0.12	0.09	0.10
BICARBONATE		163	206	205	188	194	200	196	199	229	146	185	182	204	209	218	204	201
T-ALKALINITY		144	169	168	154	159	164	161	163	188	132	154	167	168	172	179	167	165
TDS		159	169	189	167	172	177	177	176	200	142	143	175	183	184	190	188	187
COD		64.5	36.8	41.3	26.2	38.3	41.9	45.3	43.1	60.2	28.8		30.2	34.4	6.0	43.9		
NH_3-N		0.05*	0.25	0.76	0.08	0.19	0.29	0.17	0.11	0.29	0.23	0.11	0.23	0.28	0.31	0.15	0.05*	0.05*
PHOSPHATE-T		0.06	0.25	0.39	0.08	0.09	0.16	0.08	0.10	0.17	0.10	0.10	0.08	0.08	0.06	0.12	0.12	0.08
TKN		1.26	1.09	1.44	0.79	1.29	1.35	1.08	1.08	1.14	0.90	0.87	0.99	1.49	1.56	1.48	1.47	1.32
O-PO_4	0.021	0.026	0.097	0.131	0.029	0.080	0.067	0.035	0.070	0.030	0.044	0.022	0.041	0.042	0.038	0.028	0.057	0.047
NO_3-N+NO_2-N	0.024	0.024	0.047	0.015	0.007	0.057	0.041	0.035	0.208	0.051	0.091	0.349	0.024	0.112	0.169	0.100	0.500	0.053
DISCHARGE																		
TEMPERATURE °C																		
	F				F						F	F	F					

South Basin of Baptiste Lake, sampled from middle of lake, 1976-1977.
analyses supplied by the Water Quality Control Branch, Alberta Environment

	Mar.9	Mar.23	Apr.27	May 11	May 18	May 25	May 31	June 8	June 22	July 6	July 13	July 19	July 27	Aug.3	Aug.10	Aug.17	Aug.24	Aug.31
pH	7.9	7.7	8.5	8.1	8.5	8.7	8.3	8.6	7.9	9.3	7.5	8.0	7.5	7.7	7.9			8.5
CONDUCTIVITY	335	320	325	330	350	235	335	307	330	255	320	360	335	325	330			183
CALCIUM	39	37	43	37	35	16	38	32	37	22	39	38	35	36	36			17
MAGNESIUM	11	12	12	12	12	10	12	11	12	11	12	12	11	11	11			7
T-HARDNESS	142	143	158	143	140	81	144	126	143	98	144	144	133	137	135			72
SODIUM	21	20	21	20	20	19	20	21	20	19	22	22	20	20	20			11
POTASSIUM	4.0	3.8	3.9	3.8	3.8	3.6	3.9	4.0	3.9	3.6	3.8	4.5	3.9	3.8	3.9			2.2
IRON	0.07	0.05*	0.05*	0.42	0.05*	0.05*	0.08	0.05*	0.06	0.05*	0.07	0.05*	0.05*	0.05*	0.05*			0.05*
SILICA	1.0	1.3	0.8	0.05*	0.05*	0.7	0.5*	0.5*	0.7	0.5*	0.9	1.1	1.1	1.1	0.8			1.4
CHLORIDE	1*	2	2	2	2	2	2	2	2	2	1*	2	1*	2	2			2
SULPHATE	10*	10*	10*	10*	10*	10*	10*	10*	10*	21	10*	10*	10*	10*	10*			10*
FLUORIDE	0.08	0.08	0.12	0.08	0.12	0.06	0.11	0.09	0.07	0.10	0.12	0.11	0.08	0.11	0.10			0.09
BICARBONATE	208	206	177	206	202	125	198	175	201	116	188	192	189	194	195			104
T-ALKALINITY	171	169	147	169	170	105	163	147	165	117	155	158	155	159	160			87
TDS	178	186	180	186	185	123	183	167	184	147	179	184	175	178	168			101
COD		44.0	34.5	24.7	32.2		48.0		48.0	33.6	47.8	35.9	60.0	44.0	46.2			15.5
NH_3-N	0.05*	0.05*	0.16	0.19	0.21	0.17	0.12	0.09	0.15	0.09	0.07	0.17	0.19	0.23	0.25	0.26	0.34	0.10
PHOSPHATE-T	0.08	0.14	0.10	0.09	0.11	0.09	0.07	0.06	0.13	0.09	0.09	0.16	0.14	0.12	0.19	0.12	0.16	0.05*
TKN	1.26	1.52	0.93	1.08	1.71	1.24	1.38	0.75	1.37	1.04	1.48	1.50	1.67	1.56	1.42	1.45	1.43	0.49
O-PO_4	0.052	0.029	0.015	0.021	0.07	0.032	0.012	0.026	0.040	0.025	0.017	0.027	0.070	0.029	0.052	0.039	0.057	0.046
NO_2-N+NO_3-N	0.389	0.562	0.569	0.330	0.047	0.337	0.065	0.549	0.626	0.168	0.055	0.068	0.333	0.018	0.043	0.033	0.012	0.016
DISCHARGE																		
TEMPERATURE °C			F			F		F		F						F	F	F

	Sept.8	Sept.13	Sept.21	Sept.28	Oct.5	Oct.12	Oct.17	Oct.26	Nov.2	Nov.8	Nov.16							
pH		8.1	8.0	7.4	7.9	7.8	7.9	7.5	8.2	7.7	7.8							
CONDUCTIVITY		300	310	350	325	330	315	310	330	340	335							
CALCIUM		37	38	39	35	34	35	36	35	36	36							
MAGNESIUM		12	12	12	12	12	11	11	12	11	11							
T HARDNESS		140	146	144	135	133	131	135	136	137	137							
SODIUM		22	22	21	21	21	20	20	21	22	22							
POTASSIUM		4.2	3.8	4.1	3.8	3.8	3.7	3.7	3.8	3.8	3.7							
IRON		0.05*	0.05*	0.17	0.08	0.08	0.05*	0.05*	0.05*	0.05*	0.05*							
SILICA		1.6	1.0	1.4	0.8	0.6	1.0	0.5*	0.7	0.5*	0.6							
CHLORIDE		2	2	2	2	2	2	2	2	2	1							
SULPHATE		10*	10*	10*	23	10*	10*	10*	10*	13	10*							
FLUORIDE		0.10	0.10	0.12	0.13	0.10	0.11	0.13	0.09	0.09	0.09							
BICARBONATE		195	186	209	192	186	184	190	187	187	187							
T-ALKALINITY		160	153	171	158	152	151	156	153	153	154							
TDS		182	180	190	191	173	172	175	175	180	177							
COD		38.4		55.0	50.0	45.0	45.5	39.1	46.1	40.4								
NH_3-N	0.05*	0.27	0.27	2.26	0.20	0.30	0.38	0.39	0.35	0.30	0.31							
PHOSPHATE-T	0.06	0.19	0.07	0.51	0.09	0.11	0.10	0.09	0.11	0.10	0.11							
TKN	0.35	1.93	1.78	4.12	1.98	2.13	2.06	1.80	1.97	1.86	1.75							
O-PO_4	0.038	0.134	0.050	0.329	0.004	0.038	0.072	0.025	0.026	0.042	0.036							
NO_2-N+NO_3-N	0.014	0.011	0.032	0.023	0.114	0.114	0.229	0.100	0.149	0.198	0.191							
DISCHARGE																		
TEMPERATURE °C	F																	

	Mar.16	Mar.30	Apr.28	May 5	May 17	May 19	May 26	June 1	June 8	June 15	June 22	June 28	July 7	July 15	July 20	July 28	Aug.2	Aug.11
pH	7.7	8.0	8.0	8.0	8.0	8.3	8.8	8.4	7.8	7.9	7.9	8.3	8.9	7.6	8.6	7.9	8.2	8.8
CONDUCTIVITY	320	315	290	300	310	285	230	300	305	310	320	335	290	265	165	325	320	255
CALCIUM	48	37	47	42	38	42	23	36	30	34	41	41	33	20	90	29	28	32
MAGNESIUM	10	11	10	10	11	9	10	11	11	13	11	9	12	13	12	16	16	10
T-HARDNESS	161	135	159	145	138	141	100	133	121	137	145	141	132	104	70	139	135	119
SODIUM	20	19	23	18	19	19	19	19	19	19	19	21	20	16	18	20	19	14
POTASSIUM	3.4	3.4	4.0	3.8	3.8	3.9	5.3	3.6	3.7	3.9	4.0	3.9	3.5	2.7	1.7	3.0	3.6	3.0
IRON	0.1*	0.1*	0.1	0.1*	0.1*	0.1*	0.10*	0.1	0.1*	0.1	0.1*	0.1*	0.1*	0.1*	0.10*	0.1*	0.1*	0.07
SILICA																		
CHLORIDE	3	4	2	1	2	1*	1*	1*	0.1	1*	1*	1*	1*	1*	2	2	1*	5
SULPHATE	44	23	17	10*	10*	17	10*	10*	10*	10*	10*	26	10*	17	10*	19	37	10*
FLUORIDE	0.20	0.16	0.19	0.21	0.13	0.16	0.07	0.21	0.14	0.15	0.16	0.12	0.09	0.05*	0.07	0.05*	0.05*	0.13
BICARBONATE	221	205	227	206	211	208	129	204	212	203	218	214	186	186	108	203	215	175
T-ALKALINITY	182	168	186	169	173	171	119	170	174	167	179	175	173	153	94	166	176	154
TDS	239	199	214	187	187	194	140	182	180	181	183	207	183	162	115	189	210	166
COD	45.1	45.0			45.0	41.0				43.8	39.2		51.7	25.7		47.9	49.3	
NH_3-N	0.20*	0.20*	1.30	0.20*	0.20*	0.20*	0.05*	0.20	0.29	0.33	0.27	0.56	0.20*	0.75	0.15	1.05	0.44	0.49
PHOSPHATE-T	0.16	0.10	0.39	0.13	0.05	0.08	0.07	0.04	0.14	0.22	0.17	0.21	0.05	0.39	0.14	0.34	0.19	0.28
TKN	0.09	0.70	2.00	1.40	1.40	1.19	0.77	1.36	1.56	1.29	1.44	1.36	1.42	1.51	0.91	1.56	1.57	1.26
O-PO_4	0.130	0.050	0.111	0.046	0.023	0.011	0.020	0.014	0.149	0.199	0.045	0.034	0.012	0.197	0.067	0.270	0.194	0.024
NO_2-N+NO_3-N	0.510	0.217	0.047	0.157	0.182	0.010	0.049	0.062	0.319	0.245	0.191	0.123	0.045	0.028	0.003	0.041	0.090	0.002*
DISCHARGE																		
TEMPERATURE							F		F						F		F	F

	Aug.17	Aug.24	Aug.30	Sept.8	Sept.15	Sept.21	Sept.27	Oct.5	Oct.13	Oct.20	Oct.27	Nov.3	Nov.10	Dec.15	Jan.5	Jan.19	Feb.2	Feb.16
pH	8.3	8.7	8.2	7.8	8.6	7.9	7.6	7.7	7.7	8.1	8.3	8.4	8.9	8.2	8.0	7.9	7.8	7.8
CONDUCTIVITY	315	300	320	325	295	330	340	325	330	315	270	265	330	315	315	325	335	326
CALCIUM	22	30	34	53	42	34	29	36	37	35	32	27	23	29	34	36	37	41
MAGNESIUM	11	16	10	2	10	11	13	11	11	12	10	9	12	12	12	12	12	10
T HARDNESS	100	139	125	139	147	131	125	135	137	136	122	104	105	124	134	138	142	146
SODIUM	20	19	20	19	17	20	20	20	19	30	17	15	21	21	21	23	22	21
POTASSIUM	8.7	3.8	3.8	3.8	3.7	4.0	3.9	4.0	3.9	3.9	3.2	3.3	2.6	3.8	3.9	4.6	4.1	4.2
IRON	0.06	0.1*	0.1*	0.1	0.13	0.1	0.1*	1.2	12.0	0.10*	0.05*	0.05*	0.09	0.07	0.08	0.09	0.16	0.07
SILICA																		
CHLORIDE	1*	1	1	1	3	1*	1*	1	1*	3	1*	1*	2	1	1*	2	1*	2
SULPHATE	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*
FLUORIDE	0.11	0.10	0.10	0.10	0.10	0.12	0.12	0.09	0.11	0.13	0.10	0.09	0.09	0.11	0.10	0.12	0.09	0.12
BICARBONATE	217	203	209	202	208	218	221	228	229	217	194	171	140	209	215	229	206	205
T-ALKALINITY	178	167	171	166	186	179	181	187	188	178	159	142	130	171	177	188	169	168
TDS	180	180	182	178	198	187	185	195	195	201	169	141	157	170	188	199	188	192
COD		40.8	39.2	43.1	26.9	49.9	48.2	48.0	46.0	20.7	27.5		24.1	47.0	10.6	45.8		
NH_3-N	0.51	0.86	1.05	1.61	0.57	1.57	1.52	1.55	0.16	0.37	0.22	0.07	0.24	0.26	0.53	0.59	0.26	0.19
PHOSPHATE-T	0.28	0.28	0.51	0.63	0.27	0.57	0.55	0.55	0.59	0.95	0.12	0.11	0.08	0.07	0.09	0.19	0.17	0.13
TKN	1.34	1.76	2.12	2.35	1.12	2.38	2.31	2.49	2.61	1.19	0.96	0.88	1.00	1.24	1.84	1.91	1.84	1.56
O-PO_4		0.144	0.165	0.365	0.267	0.349	0.295	0.484	0.293	0.041	0.035	0.042	0.047	0.033	0.054	0.052	0.047	0.030
NO_2-N+NO_3-N		0.018	0.036	0.018	0.154	0.030	0.017	0.006	0.027	0.053	0.084	0.055	0.037	0.098	0.171	0.078	0.194	0.055
DISCHARGE																		
TEMPERATURE	F				F						F	F	F					

South Basin of Baptiste Lake, sampled from bottom of lake, 1976-1977.
analyses supplied by the Water Quality Control Branch, Alberta Environment

	Mar 9	Mar 23	Apr 27	May 1	May 18	May 25	May 31	June 8	June 22	Jul 6	Jul 13	Jul 19	Jul 27	Aug 3	Aug 10	Aug 17	Aug 24	Aug 31
pH	7.7	7.7	8.4	7.8	8.4	8.6	8.1	8.0	7.7	8.1	7.8	7.9	7.4	7.6	7.7			9.1
CONDUCTIVITY	345	320	345	330	340	254	340	321	340	290	330	370	345	335	340			234
CALCIUM	42	38	48	37	36	21	38	34	38	29	39	39	36	36	33			21
MAGNESIUM	11	12	12	12	12	10	12	11	12	10	12	12	11	11	11			9
T-HARDNESS	150	143	167	141	140	94	144	130	144	115	146	146	133	137	131			90
SODIUM	21	21	20	20	21	19	20	20	20	18	22	22	21	20	21			16
POTASSIUM	4.0	3.9	3.9	4.0	3.8	3.7	3.9	4.0	3.9	3.5	4.0	4.6	4.0	3.9	4.3			3.2
IRON	0.11	0.08	0.05*	0.08	0.05*	0.05*	0.05*	0.05*	0.05	0.05	0.06	0.08	0.10	0.05*	0.10			0.05*
SILICA	2.8	2.6	1.0	1.2	1.2	1.1	1.3	1.2	0.5*	1.5	2.0	2.3	3.0	2.0	2.5			3.6
CHLORIDE	3	2	2	2	2	2	2	2	2	2	1*	2	2	2	2			2
SULPHATE	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*			10*
FLUORIDE	0.10	0.08	0.11	0.10	0.12	0.06	0.11	0.11	0.11	0.10	0.13	0.11	0.08	0.11	0.12			0.09
BICARBONATE	2.9	2.6	179	210	201	142	200	186	208	171	194	197	197	196	203			111
T-ALKALINITY	180	177	147	172	169	118	164	153	171	140	159	162	161	161	166			114
TDS	199	193	185	188	186	136	184	173	188	148	183	187	180	179	172			129
COD		45.1	23.0	28.0	41.8		43.1		51.8	32.6	44.2	43.2	44.0	44.1	48.6			49.7
NH_3-N	0.05*	0.42	0.13	0.32	0.35	0.20	0.38	0.15	0.52	0.32	0.84	0.78	1.21	0.78	1.24	1.04	0.88	1.63
PHOSPHATE-T	0.14	0.17	0.06	0.11	0.15	0.09	0.15	0.09	0.23	0.15	0.27	0.27	0.33	0.20	0.42	1.05	0.25	0.45
TKN	1.29	2.03	0.62	1.32	2.00	1.00	1.81	1.00	1.68	1.06	2.16	2.15	2.69	2.09	2.38	1.96	1.56	2.96
O-PO_4	0.034	0.055	0.029	0.030	0.011	0.040	0.050	0.035	0.070	0.024	0.040	0.050	0.228	0.046	0.148	0.060	0.287	0.236
NO_2-N+NO_3-N	0.241	0.032	0.616	0.296	0.037	0.410	0.195	0.993	0.074	0.054	0.026	0.004	0.012	0.020	0.002*	0.015	0.002*	0.017
DISCHARGE																		
TEMPERATURE °C			F			F		F		F						F	F	F

	Sept 8	Sept 13	Sept 21	Sept 28	Oct 5	Oct 12	Oct 17	Oct 26	Nov 2	Nov 8	Nov 16							
pH		7.9	7.2	7.9	7.7	7.7	8.5	7.5	8.2	7.7	7.7							
CONDUCTIVITY		340	345	315	365	332	315	310	325	330	335							
CALCIUM		38	38	35	41	32	35	36	36	36	37							
MAGNESIUM		12	12	11	12	12	11	11	12	12	11							
T HARDNESS		143	146	132	150	130	131	137	138	137	139							
SODIUM		23	25	20	21	20	20	20	21	22	21							
POTASSIUM		4.3	4.2	3.7	4.2	3.7	3.7	3.7	3.7	3.9	3.8							
IRON		0.16	0.18	0.05*	0.20	0.12	0.05*	0.05*	0.05*	0.05*	0.05*							
SILICA		3.4	3.4	0.8	4.2	0.6	1.0	0.5*	0.5*	0.5*	0.6							
CHLORIDE		2	2	2	2	2	2	2	2	2	2							
SULPHATE		10*	10*	10*	10*	10*	10*	10*	10*	13	10*							
FLUORIDE		0.10	0.10	0.12	0.11	0.10	0.11	0.10	0.09	0.09	0.09							
BICARBONATE		206	206	184	220	186	183	189	187	187	186							
T-ALKALINITY		169	169	151	180	153	151	155	153	154	153							
TDS		189	193	173	199	171	172	175	176	180	177							
COD		40.4		40.0	52.0	40.0	43.6	35.2	49.0	40.4								
NH_3-N	1.02	2.25	2.44	0.25	2.63	0.67	0.38	0.32	0.37	0.31	0.31							
PHOSPHATE-T	1.01	0.48	1.16	0.10	0.62	0.19	0.09	0.11	0.11	0.10	0.10							
TKN	1.77	3.59	3.85	1.91	4.35	2.48	2.06	1.69	2.02	1.81	1.68							
O-PO_4	0.321	0.412	0.253	0.033	0.183	0.039	0.071	0.033	0.035	0.038	0.056							
NO_2-N+NO_3-N	0.021	0.014	0.014	0.059	0.020	0.117	0.140	0.133	0.104	0.196	0.213							
DISCHARGE																		
TEMPERATURE °C	F																	

	Mar. 16	Mar. 30	Apr. 28	May 5	May 17	May 19	May 25	June 1	June 8	June 15	June 22	June 28	July 7	July 14	July 20	Aug. 2	Aug. 11	Aug. 24
pH	8.0	8.2	8.4	8.6	8.4	8.3	8.7	8.5	8.4	8.6	8.9	9.1	8.9	8.3	8.4	7.9	8.2	8.8
CONDUCTIVITY µS cm⁻¹	345	325	270	300	310	295	245	310	330	310	310	320	280	245	170	310	205	280
CALCIUM mg l⁻¹	54	39	40	42	40	42	21	40	36	36	33	40	35	14	12	27	27	24
MAGNESIUM mg l⁻¹	11	11	11	10	11	9	12	10	11	13	11	10	11	17	7	15	10	16
T-HARDNESS mg l⁻¹	179	145	144	145	143	141	103	139	125	142	127	141	131	105	58	130	56	124
SODIUM mg l⁻¹	22	21	21	18	19	19	20	20	20	21	19	23	20	21	12	21	18	19
POTASSIUM mg l⁻¹	3.8	3.7	3.7	3.8	3.8	3.9	4.1	3.6	4.0	3.7	3.9	3.7	3.6	3.7	8.3	3.4	3.6	3.8
IRON mg l⁻¹	0.1*	0.1*	0.1	0.1	0.1*	0.1*	0.1*	0.1*	0.1*	0.1	0.1*	0.1*	0.1*	0.1*	0.10*	0.1*	0.25	0.1*
SILICA mg l⁻¹																		
CHLORIDE mg l⁻¹	3	5	3	1	3	1*	1*	1*	1*	1*	1*	9	1*	2	1*	1	3	1*
SULPHATE mg l⁻¹	43	23	10*	11	13	18	20	10*	10*	10*	10*	10*	10*	37	10*	32	10*	10*
FLUORIDE mg l⁻¹	0.22	0.16	0.20	0.20	0.16	.18	0.07	0.19	0.14	0.15	0.15	0.15	0.07	0.05*	0.05*	0.10	0.09	0.10
BICARBONATE mg l⁻¹	230	223	200	197	204	214	138	204	207	206	209	189	177	189	105	220	152	157
T-ALKALINITY mg l⁻¹	189	183	166	169	178	176	126	170	175	172	182	177	165	155	86	176	123	149
TDS mg l⁻¹	251	215	188	188	196	198	162	186	194	187	187	203	179	188	103	206	158	163
COD mg l⁻¹	81.9	28.0			48	40.0				45.7	47.3		67.3	35.2		66.5		62.6
NH_3-N mg l⁻¹	0.20*	0.20*	0.20*	0.20*	0.20*	.20*	0.05*	0.20*	0.20*	0.20*	0.20*	0.20*	0.20*	0.20*	0.05*	0.05*	0.09	0.05*
PHOSPHATE-T mg l⁻¹	.16	.10	.16	.10	.03	.06	0.07	.03	.04	.09	.08	.09	.08	0.05	0.07	.13	0.37	.09
TKN mg l⁻¹	1.20	1.00	1.20	1.60	1.34	1.02	0.74	1.32	1.69	0.99	1.88	1.52	2.02	.134	0.79	1.64	1.53	1.55
O-PO_4 mg l⁻¹	0.115	0.041	0.021	0.008	0.009	0.004	0.016	0.010	0.002	0.005	0.024	0.013	0.009	0.029	0.013	0.030	0.043	0.027
NO_2-N+NO_3-N mg l⁻¹	0.420	0.216	0.014	0.007	.019	.012	0.028	0.051	0.036	0.037	0.031	0.039	0.036	0.035	0.005	0.027	0.002*	0.015
DISCHARGE m³sec⁻¹																		
TEMPERATURE °C																		
							F							F	F		F	

	Aug. 30	Sept. 8	Sept. 15	Sept. 21	Sept. 27	Oct. 5	Oct. 20	Oct. 27	Nov. 3	Dec. 1	Dec. 8	Dec. 15	Dec. 22	Jan. 5	Jan. 19	Feb. 2	Feb. 16	Mar. 9
pH	7.6	8.4	8.3	8.3	8.8	9.0	8.5	8.9	8.8	8.5	8.2	8.3	8.7	8.2	8.2	8.0	8.2	8.0
CONDUCTIVITY µS cm⁻¹	340	295	220	300	300	290	310	220	260	305	300	315	320	320	350	350	348	350
CALCIUM mg l⁻¹	34	46	26	29	27	32	32	27	34	31	29	33	33	34	38	38	44	41
MAGNESIUM mg l⁻¹	10	3	9	11	13	11	11	9	10	13	12	12	11	13	13	13	10	12
T HARDNESS mg l⁻¹	126	127	100	119	123	125	125	103	125	130	119	131	129	138	147	148	154	150
SODIUM mg l⁻¹	21	22	14	21	21	20	26	15	17	22	21	22	22	22	21	24	23	22
POTASSIUM mg l⁻¹	3.9	4.2	2.6	3.8	3.8	3.8	3.9	2.6	5.8	3.8	3.9	4.0	4.0	3.9	3.6	4.2	4.4	4.2
IRON mg l⁻¹	0.1*	0.1*	0.05*	0.1*	0.1*	0.40	0.1*	0.05*	0.07	0.27	0.05*	0.32	0.42	0.05	0.14	0.09	0.07	0.16
SILICA mg l⁻¹																	0.5*	0.7
CHLORIDE mg l⁻¹	2	3	1*	3	1*	3	2	1*	1*	3	1*	1*	1	1*	2	1*	2	2
SULPHATE mg l⁻¹	10*	10*	10*	10*	10*	10*	10*	10*	10*	32	10*	10*	10*	10*	10*	10*	10*	10*
FLUORIDE mg l⁻¹	0.10	0.12	0.08	0.13	0.10	0.12	0.11	0.08	0.09	0.12	0.09	0.09	0.09	0.12	0.16	0.09	0.12	0.10
BICARBONATE mg l⁻¹	216	172	158	200	179	174	214	131	181	207	187	209	180	219	233	213	210	223
T-ALKALINITY mg l⁻¹	178	146	130	164	159	168	178	120	151	177	153	171	161	180	191	175	173	183
TDS mg l⁻¹	186	175	140	177	172	181	191	137	169	211	169	185	178	192	203	195	198	201
COD mg l⁻¹	131.4	51.7	26.8	54.6	49.4	51.0	44.7	25.6		43.6	39.6	42.0	46.0	11.9	43.3			
NH_3-N mg l⁻¹	0.11	0.20	0.08	0.05*	0.05*	0.11	0.08	0.07	0.06	0.20	0.10	0.16	0.27	0.15	0.05*	0.05*	0.05*	0.05*
PHOSPHATE-T mg l⁻¹	0.96	0.15	0.11	0.17	0.09	0.10	0.07	0.05	0.05*	0.05*	0.05*	0.05*	0.05*	0.05*	0.05*	0.05*	0.05*	0.05*
TKN mg l⁻¹	7.72	1.62	0.90	1.47	1.57	1.29	0.96	0.69	0.87	3.08	1.25	1.42	1.77	1.50	1.68	1.59	1.37	1.31
O-PO_4 mg l⁻¹	0.710	0.066	0.030	0.001	0.029	0.031	0.006	0.015	0.004	0.012	0.020	0.021	0.035	0.012	0.012	0.020	0.008	0.008
NO_2-N+NO_3-N mg l⁻¹	0.072	0.046	0.054	0.059	0.020	0.072	0.043	0.102	0.014	0.093	0.089	0.087	0.067	0.096	0.093	0.164	0.056	0.449
DISCHARGE m³sec⁻¹																		
TEMPERATURE °C																		
			F					F	F		F		F					

North Basin of Baptiste Lake, sampled from top of lake, 1976-1977.
analyses supplied by the Water Quality Control Branch, Alberta Environment

	Mar. 23	Apr. 27	May 11	May 18	May 25	May 31	June 22	July 6	July 13	July 19	July 27	Aug. 3	Aug. 10	Aug. 17	Aug. 24	Sept. 8	Sept. 13	Sept. 21
pH	7.9		8.5	8.5	9.3	8.4	8.7		8.8	8.9	9.3	8.9	8.9				8.2	8.1
CONDUCTIVITY μS/cm	330		330	340	225	140	320		320	340	280	310	310				300	310
CALCIUM mg/l	38		39	37	12	39	37		39	37	25	33	33				34	34
MAGNESIUM mg/l	12		12	12	10	12	12		11	12	11	11	11				12	12
T-HARDNESS mg/l	148		144	142	69	146	143		144	143	109	129	127				133	135
SODIUM mg/l	21		21	20	20	21	21		22	23	21	21	22				21	20
POTASSIUM mg/l	4.1		3.5	4.0	3.7	3.8	3.7		3.7	4.2	3.6	3.7	3.7				3.6	3.7
IRON mg/l	0.05*		0.19	0.05*	0.05*	0.05*	0.05*		0.05*	0.05*	0.05*	0.05	0.05*				0.05*	0.05*
SILICA mg/l	0.5*		0.5*	0.5*	0.5*	0.5*	0.5*		1.3	1.8	1.4	1.8	2.0				1.5	0.5*
CHLORIDE mg/l	4		2	2	2	2	2		2	2	2	2	2				2	2
SULPHATE mg/l	10*		21	10*	10*	10*	10*		10*	10*	10*	20	10*				10*	10*
FLUORIDE mg/l	0.10		0.12	0.12	0.07	0.11	0.11		0.15	0.11	0.05*	0.11	0.10				0.08	0.10
BICARBONATE mg/l	218		201	196	96	200	188		182	172	140	172	173				186	197
T-ALKALINITY mg/l	179		173	165	97	168	170		158	159	144	153	154				153	161
TDS mg/l	196		202	184	115	188	188		183	184	159	182	164				173	187
COD mg/l	49.5		33.3	31.3	34.6	62.7	50.8		46.9	56.1	58.0	53.2	62.1				51.8	
NH_3-N mg/l	0.05*	0.32	0.06	0.10	0.07	0.07	0.08	0.07	0.10	0.05*	0.11	0.14	0.06	0.24	0.19	0.12	0.25	0.10
PHOSPHATE-T mg/l	0.09	0.06	0.06	0.06	0.04	0.05*	0.05*	0.12	0.05*	0.08	0.05*	0.05*	0.12	0.12	0.07	0.06	0.09	0.05*
TKN mg/l	1.74	1.67	1.20	1.72	1.10	1.55	1.42	1.27	1.79	2.16	2.21	2.16	1.78	2.78	2.11	1.14	2.17	1.96
O-PO_4 mg/l	0.012	0.038	0.004	0.005	0.019	0.005	0.005	0.018	0.009	0.036	0.008	0.058	0.027	0.019	0.039	0.48	0.046	0.042
NO_3-N+NO_2-N mg/l	0.645	0.033	0.004	0.003	0.017	0.005	0.002*	0.006	0.003	0.004	0.003	0.012	0.002*	0.002*	0.029	0.181	0.040	0.029
DISCHARGE m^3/sec																		
TEMPERATURE °C		F			F			F						F	F	F		

	Sept. 28	Oct. 5	Oct. 12	Oct. 17	Oct. 26	Nov. 2	Nov. 9
pH	8.2	8.3	8.0	7.6	8.0	8.4	7.9
CONDUCTIVITY μS/cm	315	325	328	320	315	335	335
CALCIUM mg/l	35	36	36	35	36	35	36
MAGNESIUM mg/l	11	11	11	11	12	12	12
T HARDNESS mg/l	133	135	137	133	139	134	139
SODIUM mg/l	20	21	21	21	20	22	22
POTASSIUM mg/l	3.5	3.6	3.6	3.6	3.7	3.7	3.7
IRON mg/l	0.05*	0.05*	0.05*	0.05*	0.06	0.05*	0.05*
SILICA mg/l	0.5*	0.5*	0.5*	0.5*	0.5*	0.5*	0.5*
CHLORIDE mg/l	2	2	2	2	2	2	2
SULPHATE mg/l	10	10*	17	10*	10*	10*	16
FLUORIDE mg/l	0.12	0.11	0.12	0.11	0.12	0.11	0.09
BICARBONATE mg/l	186	194	188	185	189	188	190
T-ALKALINITY mg/l	152	160	155	152	155	155	156
TDS mg/l	181	180	184	174	177	177	185
COD mg/l	70.0	60.0	46.0	49.5	39.1	48.1	37.5
NH_4-N mg/l	0.09	0.07	0.06	0.18	0.09	0.13	0.13
PHOSPHATE-T mg/l	0.09	0.05*	0.12	0.05*	0.05*	0.05*	0.05*
TKN mg/l	2.22	2.11	1.97	1.98	1.50	1.88	1.72
O-PO_4 mg/l	0.033	0.003	0.009	0.002*	0.002*	0.002*	0.005
NO_3-N+NO_2-N mg/l	0.021	0.023	0.073	0.046	0.033	0.048	0.075
DISCHARGE m^3/sec							
TEMPERATURE °C							

	Mar.16	Mar.30	Apr.28	May 5	May 19	May 25	June 1	June 8	June 15	June 22	June 28	July 7	July 14	July 20	Aug.2	Aug.11	Aug.24	Aug.30
pH	7.8	8.1	8.2	8.2	8.2	8.7	8.2	8.1	8.3	8.4	8.9	8.9	8.3	8.9	8.2	8.3	8.7	8.3
CONDUCTIVITY	345	335	275	305	295	235	310	305	320	290	320	315	205	150	320	300	290	295
CALCIUM	55	42	39	40	42	20	39	36	36	34	40	37	17	1.0*	24	25	23	30
MAGNESIUM	11	11	11	10	9	15	10	11	13	11	10	11	13	11	15	12	16	10
T-HARDNESS	181	149	142	140	141	110	139	134	142	128	141	136	93	46	120	110	124	115
SODIUM	22	21	21	19	19	20	20	19	20	20	21	20	18	20	21	21	19	21
POTASSIUM	3.5	3.5	4.0	3.8	3.9	3.7	3.6	4.0	3.7	4.0	3.7	3.6	2.7	4.1	3.3	3.9	3.8	3.6
IRON	0.1	0.4	0.1*	0.1*	0.1*	0.1*	0.1	0.1*	0.1	0.1	0.1*	0.1*	0.1*	0.10*	0.1*	1.13	0.1*	0.1*
SILICA																		
CHLORIDE	3	4	3	1	1*	2*	1*	1*	1*	1*	8	1*	1*	2	1*	3	1*	2
SULPHATE	39	22	20	10*	17	27	21	10*	23	17	22	10*	24	10*	26	10*	10*	10*
FLUORIDE	0.20	0.15	0.19	0.21	0.16	0.07	0.19	0.14	0.14	0.14	0.12	0.07	0.05*	0.07	0.05*	0.11	0.09	0.10
BICARBONATE	242	223	206	209	208	132	182	230	215	208	201	189	162	90	215	199	163	198
T-ALKALINITY	199	183	169	172	171	119	150	189	177	171	180	175	133	82	176	163	144	162
TDS	253	213	200	187	195	164	185	194	202	189	212	187	155	96	196	173	160	174
COD	46.0	33.0			40.0				41.6	41.9		46.0	33.6		46.1		63.4	38.1
NH_3-N	0.20*	0.20*	0.20*	0.20*	0.20*	0.05*	0.20*	0.20*	0.30	0.20*	0.20*	0.51	0.20*	0.13	0.38	0.14	0.05*	0.18
PHOSPHATE-T	.13	.09	.13	.09	.05	.07	.02	.05	.12	.09	.11	.11	.05	.09	.08	0.10	.10	0.11
TKN	0.90	0.80	0.90	1.40	0.99	0.76	1.27	1.45	1.13	1.33	1.39	1.51	1.18	1.08	1.17	0.89	1.62	1.22
O-PO_4	0.131	0.057	0.045	0.010	0.011	0.002*	0.008	0.020	0.033	0.032	0.023	0.072	0.024	0.008	0.054	0.052	0.029	0.042
NO_2-N+NO_3-N	0.410	0.371	0.060	0.006	0.015	0.002*	0.044	0.029	0.063	0.044	0.042	0.041	0.040	0.005	0.038	0.015	0.015	0.025
DISCHARGE																		
TEMPERATURE °C																		
						P							F	F		F		

	Sept.8	Sept.15	Sept.21	Sept.27	Oct.5	Oct.20	Oct.27	Nov.3	Dec.1	Dec.8	Dec.15	Dec.22	Jan.5	Jan.19	Feb.2	Feb.16	Mar.9	Mar.23
pH	8.3	8.6	8.3	8.3	8.5	8.4	8.6	8.9	8.4	8.4	8.1	8.5	8.1	8.0	7.5	8.0	7.8	8.0
CONDUCTIVITY	295	250	300	305	295	310	245	185	305	305	325	330	325	350	365	350	360	350
CALCIUM	44	31	29	31	32	32	30	29	30	33	27	32	35	37	40	45	41	37
MAGNESIUM	3	10	11	11	11	11	10	5	12	11	13	12	13	13	13	11	11	12
T HARDNESS	122	119	119	123	123	125	114	92	125	128	120	129	143	145	154	158	146	143
SODIUM	23	18	21	20	20	30	17	10	22	21	24	21	22	22	24	24	22	22
POTASSIUM	4.5	3.4	3.6	3.8	3.8	3.9	3.1	4.5	3.8	3.8	4.1	3.8	3.8	3.6	4.2	4.3	4.1	4.0
IRON	0.1*	0.05*	0.1*	0.1*	0.8	0.10*	0.05*	0.05*	0.10	0.06	0.08	0.20	0.11	0.11	0.17	0.11	0.12	0.06
SILICA																2.5	2.3	0.5*
CHLORIDE	1	2	2	1*	1	2	2	1*	2	2	1	1.0*	1	2	1*	2	2	3
SULPHATE	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	36	10*	10*	10*
FLUORIDE	0.12	0.10	0.12	0.10	0.11	0.11	0.10	0.09	0.09	0.11	0.09	0.09	0.13	0.11	0.11	0.12	0.10	0.08
BICARBONATE	187	151	212	200	199	211	155	134	206	189	216	193	224	233	186	218	228	216
T-ALKALINITY	154	139	174	164	168	175	134	115	173	158	177	166	183	191	153	179	187	177
TDS	178	158	182	175	179	194	152	128	184	175	185	180	197	204	212	203	202	194
COD	49.2	24.6	46.0	40.1	53.0	47.4	24.1		41.5	24.9	40.0	41.6	8.4	45.3				47.5
NH_3-N	0.16	0.05*	0.11	0.22	0.09	0.09	0.07	0.05*	0.25	0.08	0.25	0.25	0.19	0.05*	0.11	0.05*	0.05*	0.05*
PHOSPHATE-T	0.14	0.08	0.09	0.09	0.11	0.07	0.05*	0.05*	0.05*	0.07	0.07	0.05*	0.05*	0.09	0.06	0.05*	0.06	0.07
TKN	1.55	0.59	1.33	1.32	1.26	1.03	0.71	0.79	2.44	1.15	1.89	1.52	1.51	1.68	1.62	1.36	1.30	1.67
O-PO_4	0.056	0.065	0.038	0.048	0.014	0.013	0.026	0.003	0.022	0.008	0.031	0.042	0.017	0.022	0.033	0.008	0.026	0.017
NO_2-N+NO_3-N	0.032	0.146	0.075	0.071	0.036	0.060	0.099	0.024	0.075	0.095	0.111	0.132	0.120	0.206	0.400	0.056	0.487	0.335
DISCHARGE																		
TEMPERATURE °C																		
	F	F					F	F		F		F						

North Basin of Baptiste Lake, sampled from middle of lake, 1976-1977.
analyses supplied by the Water Quality Control Branch, Alberta Environment

	Apr.27	May 11	May 18	May 25	May 31	June 22	July 6	July 13	July 19	July 27	Aug.3	Aug.10	Aug.17	Aug.24	Sept.8	Sept.13	Sept.21	Sept.28
pH		8.1	8.2	8.7	8.4	8.1		8.5	8.9	8.0	8.8	8.8				8.1	8.1	8.2
CONDUCTIVITY μS cm^{-1}		330	350	226	345	345		330	350	335	310	310				300	310	315
CALCIUM mg l^{-1}		39	36	13	38	39		39	37	35	31	30				33	34	35
MAGNESIUM mg l^{-1}		12	12	10	12	12		11	12	11	11	11				12	12	11
T-HARDNESS mg l^{-1}		146	141	73	146	146		144	143	135	125	123				132	135	132
SODIUM mg l^{-1}		21	21	18	21	22		22	23	22	21	21				21	26	20
POTASSIUM mg l^{-1}		3.5	3.8	3.3	3.8	3.9		3.7	4.2	3.8	3.6	3.7				3.8	3.6	3.6
IRON mg l^{-1}		0.15	0.05*	0.05*	0.06	0.11		0.05*	0.05*	0.05*	0.05*	0.05*				0.08	0.05*	0.05*
SILICA mg l^{-1}		0.5*	0.5*	0.5*	0.6	2.4		2.6	1.8	3.1	1.9	2.3				1.5	0.5*	0.5*
CHLORIDE mg l^{-1}		2	2	2	2	2		1*	2	2	2	2				2	2	2
SULPHATE mg l^{-1}		19	10*	10*	23	10*		10*	10*	10*	10*	10*				10*	10*	10*
FLUORIDE mg l^{-1}		0.10	0.12	0.07	0.12	0.12		0.15	0.11	0.05*	0.09	0.10				0.08	0.10	0.12
BICARBONATE mg l^{-1}		208	212	121	200	218		193	174	197	173	179				185	185	186
T-ALKALINITY mg l^{-1}		171	174	100	168	179		157	159	161	153	155				152	152	153
TDS mg l^{-1}		199	190	116	202	195		183	184	181	171	162				173	179	173
COD mg l^{-1}		29.9	46.8	16.2	42.1	54.2		54.3	51.5	49.0	55.5	53.1				50.9		55.0
NH_3-N mg l^{-1}	0.10	0.09	0.14	0.05*	0.08	0.28	0.05*	0.21	0.09	0.58	0.12	0.13	0.34	0.13	0.08	0.06	0.05*	0.11
PHOSPHATE-T mg l^{-1}	0.05*	0.07	0.06	0.03	0.05*	0.12	0.06	0.05*	0.08	0.13	0.05*	0.11	0.08	0.05*	0.05*	0.08	0.05*	0.07
TKN mg l^{-1}	1.09	1.20	1.78	0.45	1.51	1.43	0.60	1.59	1.98	2.23	2.03*	1.71	1.60	2.14	0.73	1.81	1.73	2.24
O-PO_4 mg l^{-1}	0.026	0.006	0.003	0.008	0.008	0.035	0.002*	0.006	0.030	0.080	0.072	0.026	0.015	0.023	0.047	0.034	0.036	0.011
NO_3-N+NO_2-N mg l^{-1}	0.102	0.019	0.003	0.013	0.008	0.005	0.002*	0.005	0.004	0.016	0.019	0.005	0.021	0.009	0.046	0.049	0.026	0.020
DISCHARGE m^{3}sec^{-1}																		
TEMPERATURE °C				F			F						F	F	F			

	Oct.5	Oct.12	Oct.17	Oct.26	Nov.2	Nov.9
pH	8.2	8.1	8.5	7.9	8.4	8.0
CONDUCTIVITY μS cm^{-1}	325	330	320	315	335	335
CALCIUM mg l^{-1}	34	34	33	37	36	37
MAGNESIUM mg l^{-1}	11	12	12	11	12	11
T HARDNESS mg l^{-1}	131	135	131	139	138	139
SODIUM mg l^{-1}	21	22	21	20	22	22
POTASSIUM mg l^{-1}	3.6	3.6	3.6	3.6	3.8	3.7
IRON mg l^{-1}	0.08	0.05	0.05*	0.05*	0.05*	0.05*
SILICA mg l^{-1}	0.5*	0.5*	0.5*	0.5*	0.5*	0.5*
CHLORIDE mg l^{-1}	2	2	2	2	2	2
SULPHATE mg l^{-1}	25	10*	10*	10*	10*	13
FLUORIDE mg l^{-1}	0.11	0.10	0.11	0.10	0.09	0.09
BICARBONATE mg l^{-1}	195	188	185	189	186	191
T-ALKALINITY mg l^{-1}	160	154	153	155	155	156
TDS mg l^{-1}	194	176	174	177	178	182
COD mg l^{-1}	57.0	46.0	51.5	37.1	48.1	40.4
NH_3-N mg l^{-1}	0.06	0.06	0.11	0.11	0.11	0.09
PHOSPHATE-T mg l^{-1}	0.05*	0.08	0.05*	0.05*	0.05*	0.05*
TKN mg l^{-1}	2.02	2.31	1.90	1.61	1.89	1.69
O-PO_4 mg l^{-1}	0.002*	0.009	0.002*	0.002*	0.003*	0.004
NO_3-N+NO_2-N mg l^{-1}	0.031	0.319	0.044	0.042	0.043	0.064
DISCHARGE m^{3}sec^{-1}						
TEMPERATURE °C						

	Mar. 16	Mar. 30	Apr. 26	May 5	May 17	May 19	May 25	June 1	June 8	June 15	June 22	June 28	July 7	July 14	July 20	Aug. 2	Aug. 11	Aug. 24
pH	7.7	7.8	8.1	8.0		8.3	8.3	8.2	8.1	8.0	8.4	9.0	8.9	8.0	8.5	7.8	8.8	8.2
CONDUCTIVITY	315	375	275	305	310	295	270	310	310	320	315	320	305	265	315	360	235	325
CALCIUM	57	44	40	42	40	42	20	38	32	36	36	39	38	22	27	36	37	31
MAGNESIUM	9	12	11	10	11	9	15	11	12	13	10	11	10	13	15	15	7	17
T-HARDNESS	182	159	146	145	143	141	110	139	129	142	131	141	136	110	130	150	120	148
SODIUM	20	24	21	19	19	19	20	20	24	19	21	23	20	14	21	21	11	19
POTASSIUM	3.4	3.7	3.9	3.8	3.8	3.9	6.6	3.6	4.0	3.9	4.0	3.6	3.6	3.0	4.1	3.6	2.6	4.0
IRON	0.1	0.2	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*	0.1	0.1	0.1*	0.1*	0.1*	0.10*	0.1	1.03	0.1*
SILICA																		
CHLORIDE	3	4	2	1	3.0	1*	1*	1*	1*	1*	1*	17	1*	1*	1*	1*	3	2
SULPHATE	46	27	18	10*	13	16	21	10*	10*	10*	13	10*	10*	25	10*	27	10*	10*
FLUORIDE	0.20	0.19	0.20	0.20	.16	0.16	0.07	0.19	0.14	0.14	0.15	0.14	0.07	0.05*	0.07	0.05*	0.09	0.10
BICARBONATE	224	253	209	209	214	217	169	216	215	215	218	204	195	192	198	239	166	215
T-ALKALINITY	184	208	171	172	178	178	138	177	176	177	171	168	160	158	173	196	144	177
TDS	250	234	200	189	196	198	166	190	189	189	187	216	191	173	188	221	158	189
COD	56.1	31.0			48.0	34.0				39.4	40.5		49.6	28.0		51.2		53.8
NH_3-N	0.20*	1.10	0.20*	0.20*	.20*	0.27	0.09	0.20*	0.20*	0.32	0.20*	0.20*	0.61	0.48	0.40	2.07	1.75	1.80
PHOSPHATE-T	.16	.33	.10	.10	0.03	.05	0.07	.04	.07	.26	.27	.10	.20	.14	0.18	.52	0.69	.45
TKN	1.2	1.5	1.0	1.5	1.34	0.97	0.89	1.14	1.64	1.47	1.66	1.30	1.65	1.51	1.00	2.59	2.61	2.49
O-PO_4	0.071	0.198	0.026	0.014	.009	0.005	0.016	0.007		0.550	0.163	0.015	0.158	0.383	0.175	0.300		0.170
NO_2-N+NO_3-N	0.081	0.036	0.045	0.035	.019	0.012	0.004	0.047	-	0.057	0.032	0.043	0.022	0.024	0.002*	0.026		0.021
DISCHARGE																		
TEMPERATURE °C							P							P	P		P	

	Aug. 30	Sept. 8	Sept. 15	Sept. 21	Sept. 27	Oct. 5	Oct. 20	Oct. 27	Nov. 3	Dec. 1	Dec. 8	Dec. 15	Dec. 22	Jan. 5	Jan. 19	Feb. 2	Feb. 16	Mar. 9
pH	8.5	8.3	8.2	8.2	8.2	8.5	8.4	8.6	8.4	8.4	8.4	8.1	8.7	7.9	7.9	7.8	7.8	7.7
CONDUCTIVITY	350	295	235	300	310	295	310	235	215	305	310	345	360	355	390	380	410	460
CALCIUM	35	44	28	30	28	32	33	27	20	31	36	34	36	41	41	41	52	49
MAGNESIUM	14	3	9	11	13	11	11	9	7	13	11	13	13	12	13	14	11	14
T HARDNESS	145	122	106	121	125	123	127	106	78	128	136	138	141	150	157	160	177	181
SODIUM	21	22	14	20	20	21	26	16	10	22	21	26	24	25	20	27	29	32
POTASSIUM	4.1	42	2.7	3.8	3.8	3.8	3.7	2.6	2.0	3.7	3.8	4.1	3.9	4.0	3.6	4.3	4.6	46
IRON	0.1*	0.1*	0.05*	0.1*	0.2	0.4	0.10*	0.05*	0.05*	0.09	0.09	0.19	0.23	0.23	0.18	0.20	0.18	0.76
SILICA																	6.7	9.7
CHLORIDE	1	1	1*	2	1	1	3	1*	1*	2	1*	1	1*	1	1	1*	4	3
SULPHATE	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	25	10*	17	10*	10*	10*	23	20
FLUORIDE	0.10	0.10	0.08	0.12	0.12	0.10	0.13	0.08	0.13	0.09	0.09	0.13	0.11	0.12	0.11	0.09	0.13	0.10
BICARBONATE	225	184	161	194	200	163	205	161	151	209	200	235	207	248	239	243	258	299
T-ALKALINITY	184	151	137	159	164	163	171	140	125	177	167	193	185	204	196	199	212	245
TDS	196	175	144	173	176	176	189	150	115	187	196	194	205	216	207	216	251	270
COD	69.1	80.2	27.6	44.7	47.8	54.9	43.9	22.6		4.17	36.5	44.1	26.7	17.5	51.8			
NH_3-N	0.24	0.16	0.06	0.17	0.33	0.11	0.09	0.07	0.05*	0.39	0.14	0.47	0.37	0.53	0.05*	0.37	0.85	0.19
PHOSPHATE-T	0.89	0.15	0.09	0.10	0.12	0.16	0.11	0.05*	0.05*	0.05*	0.06	0.09	0.07	0.06	0.27	0.10	0.31	0.51
TKN	4.72	1.51	0.82	1.48	1.43	1.80	0.94	0.62	0.70	2.05	1.05	1.11	1.43	1.83	2.19	2.07	2.60	1.62
O-PO_4	0.610	0.049	0.028	0.050	0.049	0.015	0.008	0.016	0.004	0.019	0.019	0.040	0.044	0.031	0.101	0.037	0.082	0.502
NO_2-N+NO_3-N	0.021	0.028	0.128	0.068	0.041	0.037	0.037	0.070	0.035	0.065	0.062	0.057	0.113	0.057	0.037	0.036	0.044	0.002*
DISCHARGE																		
TEMPERATURE °C			P					P	P		P		P					

North Basin of Baptiste Lake, sampled from bottom of lake, 1976-1977.
analyses supplied by the Water Quality Control Branch, Alberta Environment

	Mar. 23	Apr. 27	May 11	May 18	May 25	May 31	June 22	July 6	July 13	July 19	July 27	Aug. 3	Aug. 10	Aug. 17	Aug. 24	Sept. 11	Sept. 21	Sept. 28
pH	7.9		7.8	8.3	8.4	8.3	7.8		7.6	8.0	7.8	7.7	7.8			8.3	7.9	8.2
CONDUCTIVITY µmho	410		340	340	280	345	340		345	375	380	350	360			300	315	315
CALCIUM mg/l	44		39	36	20	36	40		43	40	35	39	38			35	34	36
MAGNESIUM mg/l	14		12	12	10	12	12		11	12	11	11	12			12	12	11
T-HARDNESS mg/l	165		146	141	92	142	148		154	148	135	144	142			135	135	134
SODIUM mg/l	27		21	21	20	21	22		23	23	22	21	22			21	27	21
POTASSIUM mg/l	4.3		4.0	4.0	3.8	3.9	3.9		4.1	4.1	4.2	3.8	4.2			3.8	3.7	3.5
IRON mg/l	0.15		0.28	0.05*	0.07	0.10	0.07		0.63	0.05*	0.06	0.06	0.08			0.05*	0.05*	0.06
SILICA mg/l	6.2		2.5	0.5*	1.2	1.8	3.7		5.3	4.8	5.8	5.6	6.5			1.6	1.2	0.5*
CHLORIDE mg/l	3		2	2	2	2	2		1*	2	2	2	2			2	6	2
SULPHATE mg/l	10*		10*	10*	10*	10*	10*		10*	10*	10*	10*	10*			10*	10*	10*
FLUORIDE mg/l	0.10		0.10	0.15	0.07	0.11	0.11		0.15	0.12	0.10	0.09	0.10			0.08	0.13	0.12
BICARBONATE mg/l	264		215	204	150	206	218		207	204	208	208	216			185	189	186
T-ALKALINITY mg/l	216		176	168	124	169	179		170	167	171	171	177			152	155	153
TDS mg/l	231		194	186	141	187	196		194	192	187	190	184			174	185	175
COD mg/l	51.3		29.6	39.6	30.8	61.7	47.7		38.6	44.2	49.0	49.1	55.3			48.5		55.0
NH_3-N mg/l	0.69	0.19	0.49	0.14	0.07	0.11	0.50	0.07	1.08	0.91	1.72	1.92	2.46	1.67	1.89	0.16	0.28	0.08
PHOSPHATE-T mg/l	0.31	0.06	0.15	0.08	0.06	0.07	0.16	0.05*	0.29	0.26	0.36	0.30	0.59	0.32	0.35	0.07	0.08	0.06
TKN mg/l	2.31	1.15	1.44	1.67	0.99	1.48	1.70	0.85	2.34	2.37	1.50	3.08	3.42	2.99	3.25	1.85	2.01	2.17
O-PO_4 mg/l	0.073	0.003	0.032	0.005	0.048	0.031	0.043	0.007	0.056	0.042	0.221	0.142	0.164	0.329	0.290	0.040	0.040	0.032
NO_3-N+NO_2-N mg/l	0.0030*	0.053	0.028	0.018	0.027	0.011	0.002*	0.004	0.003	0.007	0.009	0.009	0.003	0.004	0.003	0.052	0.029	0.037
DISCHARGE ft^3/sec																		
TEMPERATURE °C		F			F			F					F	F				

	Oct. 5	Oct. 12	Oct. 17	Oct. 26	Nov. 2	Nov. 9
pH	8.2	8.1	8.7	7.9	8.4	7.8
CONDUCTIVITY µmho	325	334	325	315	335	335
CALCIUM mg/l	35	34	35	36	36	37
MAGNESIUM mg/l	11	12	11	11	12	11
T HARDNESS mg/l	133	138	133	137	138	139
SODIUM mg/l	22	21	21	20	22	22
POTASSIUM mg/l	3.7	3.5	3.5	3.6	3.8	3.7
IRON mg/l	0.09	0.05*	0.05*	0.05*	0.05*	0.05*
SILICA mg/l	0.5*	0.5*	0.5*	0.5*	0.5*	0.5*
CHLORIDE mg/l	2	2	1	2	2	2
SULPHATE mg/l	22	10*	16	10*	10*	13
FLUORIDE mg/l	0.09	0.10	0.11	0.10	0.09	0.09
BICARBONATE mg/l	196	188	188	190	189	190
T ALKALINITY mg/l	160	154	155	156	154	156
TDS mg/l	193	175	181	177	178	182
COD mg/l	59.0	46.0	47.5	39.1	50.0	41.4
NH_3-N mg/l	0.06	0.17	0.11	0.09	0.13	0.11
PHOSPHATE-T mg/l	0.05*	0.06	0.05*	0.05*	0.05*	0.05*
TKN mg/l	1.96	21.3	1.93	1.48	1.89	1.68
O-PO_4 mg/l	0.002*	0.002*	0.002*	0.002*	0.004	0.015
NO_3-N+NO_2-N mg/l	0.030	0.044	0.046	0.047	0.041	0.069
DISCHARGE ft^3/sec						
TEMPERATURE °C						

APPENDIX VII

GROUNDWATER CHEMISTRY DATA

Groundwater Chemistry: Peizometer 1B

LSD 4-15-67-24-W4M

(all analyses in mg/L)

Date	Ca	Mg	Na	K	Cl	SO4	HCO3	CO3	F	Fe	Si
1977											
Aug 10:	31	11	452	2.3	280	117	754	<5	0.64	1.45	10.2
Aug 16:	31	11	452	2.6	269	118	747	6	0.66	10.47	8.5
Aug 23:	7	10	410	3.5	207	150	638	<5	0.28	8.70	6.1
Aug 30:	7	11	354	3.3	134	179	480	40	0.42	0.16	6.2
Sep 6:	47	14	375	3.6	128	231	716	6	0.55	6.36	8.7
Sep 14:	45	14	375	3.6	123	222	696	7	0.57	6.34	8.7
Sep 20:	46	15	365	3.1	112	236	666	-	0.52	<.05	8.8
Sep 27:	48	16	375	3.3	101	224	733	-	0.58	10.47	9.6
Oct 4:	16	9	218	1.8	62	140	407	-	0.52	0.31	4.6
Oct 19:	9	14	365	3.4	100	220	605	<5	0.50	0.18	7.5
Oct 26:	25	14	350	3.1	93	214	635	-	0.40	6.30	8.5
Nov 1:	50	16	365	3.3	92	233	735	-	0.52	7.95	9.6
Nov 8:	35	15	365	3.4	99	230	716	<5	0.53	7.52	9.6
Nov 15:	51	16	365	3.0	98	241	732	<5	0.47	7.53	10.5
Nov 22:	48	16	360	4.1	103	235	719	6	0.53	6.97	9.8
Nov 30:	50	15	370	3.2	95	229	697	15	0.65	7.67	9.6
Dec 7:	48	15	356	2.9	95	231	732	-	0.52	8.04	9.4
Dec 21:	27	15	390	3.5	94	224	669	-	0.39	9.21	5.8
1978											
Jan 3:	47	15	365	3.2	93	233	723	<5	0.53	6.86	8.6
Jan 10:	48	15	356	2.9	95	234	713	9	0.56	7.70	9.6
Jan 25:	34	15	356	2.8	91	227	737	-	0.52	9.05	9.2
Jun 27:	44	15	359	3.1	94	230	744	-	0.50	9.90	9.6
Jul 25:	49	14	350	2.6	92	244	733	<5	0.46	11.24	9.1
Aug 14:	44	16	354	2.8	90	246	736	<5	0.50	11.32	9.5

*analysed by the Pollution Control Lab, Alberta Environment

Groundwater Chemistry: Piezometer 1B

(all analyses in mg/L, except conductivity which is in microsiemens/cm)

Date 1977	TDS	Cond	TIC	TOC	NO3+NO2	TkN	O-PO4	T-PO4
Aug 10:	1269	2150	150	7	0.010	2.36	0.167	0.71
Aug 16:	1258	2200	149	13	0.010	2.63	0.054	0.43
Aug 23:	1107	1925	129	30	0.018	2.69	0.047	1.16
Aug 30:	965	1604	126	24	0.003	1.81	0.031	0.41
Sep 6:	1158	1850	129	12	0.033	2.73	0.040	0.58
Sep 14:	1133	1825	129	<2	0.014	2.95	0.047	0.63
Sep 20:	1115	1850	134	12	0.016	3.13	0.046	1.26
Sep 27:	1128	1850	128	17	0.005	2.80	0.027	0.68
Oct 4:	646	1106	87	4	0.020	2.69	0.015	0.75
Oct 19:	1009	1666	137	3	0.016	1.16	0.067	0.32
Oct 26:	1011	1656	130	18	0.034	1.80	0.052	0.50
Nov 1:	1121	1850	144	7	0.008	2.70	0.255	0.69
Nov 8:	1103	1850	136	8	0.011	64.80	0.016	0.72
Nov 15:	1137	1870	129	26	0.017	2.56	0.018	0.72
Nov 22:	1126	1733	147	15	0.025	2.89	0.036	0.63
Nov 30:	1120	1743	150	9	0.022	13.33	0.016	0.74
Dec 7:	1108	1773	129	36	0.026	2.77	0.016	0.88
Dec 21:	1082	1691	138	12	0.026	2.42	0.067	0.59
Jan 3:	1104	1753	154	<2	0.011	2.50	0.019	0.56
Jan 10:	1112	1750	140	16	0.021	2.66	0.027	0.63
Jan 25:	1089	1754	129	37	0.013	2.44	0.027	0.70
Jun 27:	1111	1763	137	-	0.017	2.29	0.041	-
Jul 25:	1115	1791	150	-	0.068	2.10	0.057	-
Aug 14:	1118	1760	156	9	0.002	2.63	0.044	0.72

*analysed by the Pollution Control Lab, Alberta Environment

Groundwater Chemistry: Piezometer 2B

LSD 1-21-66-24-W4M

(all analyses in mg/L)

Date	Ca	Mg	Na	K	Cl	SO4	HCO3	CO3	F	Fe	Si
1977											
Aug 10:	<2	2	298	1.8	22	81	707	14	0.40	8.19	7.3
Aug 16:											
Aug 23:											
Aug 30:	<2	1	312	1.7	25	75	667	27	0.42	0.33	3.2
Sep 6:	2	2	308	1.7	23	75	678	25	0.42	3.38	2.5
Sep 14:	4	2	318	1.8	24	73	667	31	0.43	3.43	2.4
Sep 20:	2	2	308	1.7	22	79	654	14	0.37	<.05	2.1
Sep 27:	3	2	317	1.6	22	74	685	21	0.47	4.37	2.3
Oct 4:	<2	1	194	0.9	13	40	438	13	0.53	0.40	1.4
Oct 18:											
Oct 26:	<2	2	300	1.7	22	64	632	39	0.40	1.02	2.2
Nov 1:	3	2	288	1.6	22	72	644	43	0.44	1.59	1.4
Nov 8:	3	2	302	1.7	23	83	655	37	0.43	1.59	1.0
Nov 15:	2	1	317	1.7	30	84	641	42	0.41	1.63	1.3
Nov 22:	<2	2	300	1.6	24	64	640	42	0.43	1.56	1.6
Nov 30:	<2	2	315	1.6	24	61	638	45	0.53	1.53	1.2
Dec 7:	<2	2	308	1.6	23	66	647	40	0.41	1.61	1.3
Dec 21:	<2	2	270	1.4	21	53	579	35	0.38	1.47	0.8
1978											
Jan 3:	<2	2	302	1.7	23	60	631	49	0.41	1.42	1.0
Jan 10:	<2	2	308	1.6	25	57	613	58	0.46	1.50	1.0
Jan 25:	<2	1	298	1.6	23	58	634	47	0.41	1.69	1.4
Feb 13:	<2	2	300	1.4	25	62	624	53	0.41	1.33	1.0
Mar 8:	<2	2	298	1.6	24	57	513	57	0.42	1.14	1.0
Jun 27:	2	<1	315	1.8	27	58	698	18	0.42	2.11	4.1
Jul 25:	<2	2	320	1.6	28	65	687	24	0.42	1.78	3.6

*analysed by the Pollution Control Lab, Alberta Environment

Groundwater Chemistry: Piezometer 2B

(all analyses in mg/L, except conductivity which is in microsiemens/cm)

Date	TDS	Cond	TIC	TOC	NO3+NO2	TkN	O-PO4	T-PO4
1977								
Aug 10:	768	1295	148	4	0.006	1.46	0.008	0.08
Aug 16:								
Aug 23:	-	-	132	<2	0.017	0.67	0.031	<.05
Aug 30:	772	1282	133	8	0.003	1.26	0.007	<.05
Sep 6:	770	1280	-	-	0.006	1.67	0.029	<.05
Sep 14:	781	1100	125	11	0.012	1.65	0.041	<.05
Sep 20:	752	1280	134	12	0.010	1.66	0.015	<.05
Sep 27:	778	1280	131	10	0.004	1.80	0.010	<.05
Oct 4:	479	831	122	<2	0.019	1.21	0.013	<.05
Oct 19:								
Oct 26:	739	1254	123	27	0.017	1.18	0.014	<.05
Nov 1:	749	1310	122	9	0.010	1.76	0.011	<.05
Nov 8:	773	1350	138	4	0.012	1.72	0.007	<.05
Nov 15:	794	1310	133	14	0.009	1.61	0.011	<.05
Nov 22:	750	1288	142	10	0.022	1.81	0.022	<.05
Nov 30:	764	1268	136	<2	0.019	2.85	0.018	<.05
Dec 7:	760	1276	126	22	0.017	1.76	0.029	<.05
Dec 21:	668	1132	134	12	0.024	1.73	0.022	<.05
1978								
Jan 3:	750	1263	142	14	0.017	1.76	0.018	<.05
Jan 10:	753	1261	144	6	0.031	1.75	0.016	<.05
Jan 25:	742	1266	121	33	0.012	1.61	0.035	<.05
Feb 13:	751	1272	140	10	0.013	1.66	0.038	<.05
Mar 8:	743	1275	134	<2	0.013	1.76	0.047	0.07
Jun 27:	767	1280	125	<2	0.011	1.68	0.019	0.03
Jul 25:	780	1285	150	-	0.057	1.82	0.014	-

*analysed by the Pollution Control Lab, Alberta Environment

Groundwater Chemistry: Piezometer 3B

LSD 6-21-66-24-W4M

(all analyses in mg/L, except conductivity which is in microsiemens/cm)

Date 1977	Ca	Mg	Na	K	Cl	SO4	HCO3	CO3	F	Fe	Si
Oct 8:	8.4	2	281	1.6	26	28	694	<5	0.55	0.88	11.5

Date 1977	TDS	Cond	TIC	TOC	NO3+NO3	TkN	O-PO4	T-PO4
Oct 8:	689	1210	-	-	<0.1	-	-	-

*analysed by the Pollution Control Lab, Alberta Envirnment

Groundwater Chemistry from the Water Table Wells

(all analyses in mg/L)

Well No.	Location (W4M)	Sampling Date	Ca	Mg	Na	K	HCO3	SO4	Cl
1	1-26-66-24	9/8/78	337	115	30	5.9	493	263	500
2	3-26-66-24	8/8/78	113	41	23	4.6	564	55	<1
3	16-27-66-24	damaged							
4	6-22-66-24	8/8/78	120	42	14	3.7	584	61	2
5	5-22-66-24	8/8/78	38	11	189	3.5	622	61	2
6	7-21-66-24	lost							
7	10-21-66-24	8/8/78	176	47	29	1.6	500	316	5
8	12-21-66-24	8/8/78	228	17	17	2.2	292	31	<1
9	2-28-66-24	8/8/78	121	41	27	2.2	566	137	<1
10	4-28-66-24	8/8/78	10	2	7	7.7	42	<10	<1
11	4-33-66-24	9/8/78	107	72	12	6.8	790	55	3
12	9-29-66-24	8/8/78	96	25	28	3.2	422	61	2
13	8-33-66-24	8/8/78	98	17	8	2.0	360	33	<1
14	1- 3-67-24	8/8/78	52	17	168	5.3	582	133	<1
15	16- 3-67-24	8/8/78	158	52	67	5.8	771	244	2
16	15-10-67-24	8/8/78	103	26	5	2.2	385	55	2
17	8-15-67-24	9/8/78	56	18	130	3.7	526	65	2
18	10-11-67-24	destroyed							
19	4-13-67-24	9/8/78	138	49	36	4.1	590	55	45
20	4-12-67-24	8/8/78	136	46	34	6.7	636	113	3
21	16-34-66-24	9/8/78	123	47	7	3.8	645	28	2
22	2- 2-66-24	8/8/78	84	25	3	4.6	632	61	<1
23	11-35-66-24	9/8/78	94	34	181	6.6	574	158	<1

*analysed by the Pollution Control Lab, Alberta Environment

Groundwater Chemistry from Water Table Wells

(all analyses in mg/L, except conductivity which is in microsiemens/cm)

Well No.	Location (W4M)	Si	Fe	F	NO2+NO3	TDS	Cond.
1	1-26-66-24	19.0	0.55	0.14	0.10	1494	2640
2	3-26-66-24	16.4	0.24	0.15	<.05	516	919
3	16-27-66-24	damaged					
4	6-22-66-24	15.2	1.15	0.13	0.06	532	942
5	5-22-66-24	11.6	0.26	0.38	0.06	611	1018
6	7-21-66-24	destroyed					
7	10-21-66-24	11.7	1.40	0.17	<.05	821	1206
8	12-21-66-24	17.0	0.75	0.13	2.18	218	514
9	2-28-66-24	12.9	1.29	0.21	0.06	609	1021
10	4-28-66-24	9.5	4.00	0.05	0.84	57	98
11	4-33-66-24	18.3	0.74	0.12	0.15	645	1167
12	9-29-66-24	12.4	1.21	0.13	0.12	422	738
13	8-33-66-24	18.2	1.10	0.19	0.06	334	603
14	1- 3-67-24	13.4	0.58	0.29	0.10	663	1088
15	16- 3-67-24	14.5	0.43	0.13	0.08	909	1441
16	15-10-67-24	12.1	0.49	0.21	2.64	395	687
17	8-15-67-24	14.4	0.49	0.20	0.10	534	875
18	10-11-67-24	destroyed					
19	4-13-67-24	17.5	0.37	0.11	0.08	618	1073
20	4-12-67-24	14.5	0.17	0.08	0.12	652	1080
21	16-34-66-24	22.1	0.12	0.21	0.12	529	843
22	2- 2-66-24	5.1	0.17	0.12	0.06	550	1002
23	11-35-66-24	17.0	0.93	0.18	0.12	791	1226

*analysed by the Polution Control Lab, Alberta Environment

Groundwater Chemistry: Water Table Wells

(all analyses in mg/L, except conductivity which is in microhmos)

Well No.	Location (W4M)	Na	HCO3	SO4	Cl	Cond.
1	1-26-66-24	29	725	280	810	3510
2	3-26-66-24	22	541	54	<2.5	848
3	16-27-66-24	9	417	7	<2.5	620
4	6-22-66-24	16	552	62	<2.5	848
5	5-22-66-24	214	597	65	<2.5	960
6	7-21-66-24	43	767	22	<2.5	1090
7	10-21-66-24	33	493	320	5.0	1095
8	12-21-66-24	7	255	12	<2.5	432
9	2-28-66-24	32	-	167	<2.5	995
10	4-28-66-24	6	-	20	3.0	98
11	4-33-66-24	9	-	52	<2.5	1050
12	9-29-66-24	destroyed				
13	8-33-66-24	7	-	31	<2.5	575
14	1- 3-67-24	21	-	59	<2.5	890
15	16- 3-67-24	73	-	250	<2.5	1385
16	15-10-67-24	4	-	50	<2.5	645
17	8-15-67-24	95	-	34	<2.5	670
18	10-11-67-24	lost				
19	4-13-67-24	destroyed				
20	4-12-67-24	174	-	150	<2.5	1000
21	16-34-66-24	6	-	20	<2.5	805
22	2- 2-66-24	2	-	61	<2.5	1020

*analysed at the Geology Dept, Univ. of Alberta on 14/10/78

APPENDIX VIII

PHYSICAL GROUNDWATER DATA

Summary of the Shallow Test-Hole Drilling Program

Obser. Well #	Location	Total Depth	Depth to Water	Slotted Interval	Aquifer Lithology
1	1-26-66-24-W4M	7.6m	6.4m	4.6- 7.6m	sandy-till
2	3-26-66-24-W4M	6.1m	5.2m	1.5- 6.1m	sand
3	16-27-66-24-W4M	4.6m	2.6m	1.5- 4.6m	sand
4	6-22-66-24-W4M	4.6m	1.5m	1.8- 4.6m	clayey-till
5	5-22-66-24-W4M	7.6m	6.4m	5.2- 7.6m	sandy-till
6	7-21-66-24-W4M	3.0m	0.9m	0.6- 3.0m	sandy-till
7	10-21-66-24-W4M	3.0m	0.6m	0.3- 3.0m	sand
8	12-21-66-24-W4M	6.1m	4.6m	1.5- 6.1m	sand
9	2-28-66-24-W4M	4.6m	2.7m	0.9- 3.7m	sand
10	4-28-66-24-W4M	9.1m	6.7m	4.6- 9.1m	sand
11	4-33-66-24-W4M	12.2m	11.6m	7.6-12.2m	clayey-till
12	9-29-66-24-W4M	3.0m	1.8m	0.6- 3.0m	sand
13	8-33-66-24-W4M	12.2m	11.0m	6.1-12.2m	clayey-till
14	1- 3-67-24-W4M	10.7m	9.5m	6.1-10.7m	clayey-till
15	16- 3-67-24-W4M	9.1m	7.9m	3.0- 9.1m	clayey-till
16	15-10-67-24-W4M	4.6m	3.0m	1.5- 4.6m	sand
17	8-15-67-24-W4M	12.2m	11.0m	6.1-12.2m	clayey-till
18	10-11-67-24-W4M	10.7m	10.1m	6.1-10.7m	clayey-till
19	4-13-67-24-W4M	6.1m	4.6m	2.4- 6.1m	clayey-till
20	4-12-67-24-W4M	15.2m	14.3m	12.5-15.2m	clayey-till
21	16-34-66-24-W4M	9.1m	7.3m	5.5- 9.1m	clayey-till
22	2- 2-66-24-W4M	3.0m	0.9m	0.6- 3.0m	sandy-till
23	11-35-66-24-W4M	12.2m	10.7m	7.6-12.2m	sandy-till
24	16-17-66-24-W4M	15.2m	-	no piezometer	
25	14-28-66-24-W4M	9.1m	8.2m	no piezometer	

Summary of the Deep Test-Hole Drilling Program

Test Hole No.	Location	Drilling[1] Date	Depth	Bedrock Depth (Elev.[2])	Remarks:
76-1	4-15-67-24-W4M	1	54.9m	43.0m (545m)	flowing; 14 L/min
76-2	1-20-66-24-W4M	1	102.1m	98.2m (485m)	flowing; 45 L/min
76-3	13-36-66-24-W4M	1	56.7m	41.2m (545m)	
76-4	12-26-66-24-W4M	1	36.6m	20.1m (560m)	
76-5	12-36-66-24-W4M	1	73.2m	62.5m (525m)	
76-8	13-33-66-24-W4M	1	30.5m	20.4m (580m)	
76-11	14-12-67-24-W4M	1	42.7m	7.6m (590m)	
77-1	6-21-66-24-W4M	2	21.9m	17.1m (570m)	
77-2	6-21-66-24-W4M	2	51.8m	47.2m (540m)	flowing; 40 L/min static; 2.1m ags[3] piezometer 3B
77-3	4-15-67-24-W4M	2	29.0m	- (-)	flowing; 15 L/min static; 7.0m ags[3] piezometer 1B
77-4	7-10-67-24-W4M	2	19.8m	13.1m (565m)	
77-5	8-10-67-24-W4M	2	27.4m	14.6m (570m)	
77-6	1-20-66-24-W4M	2	82.3m	59.4m (530m)	flowing; 10 L/min static; 9.8m ags[3] piezometer 2B

[1]: 1 = Dec 6 to Dec 10, 1976
2 = Jul 17 to Aug 3, 1977
[2]: elevations are m a.m.s.l.
[3]: ags = above ground surface

Depth to Water in the Water Table Wells

Well No.	Date: 1978 Jun 8	Jun 28	Aug 8	Aug 12	Oct 14
1	2.79m	2.90m	-	3.30m	2.46m
2	0.33m	0.86m	1.38m	-	0.38m
3	2.69m	2.73m	2.81m	-	1.94m
4	0.88m	1.18m	1.29m	-	0.75m
5	0.65m	1.09m	1.40m	-	0.61m
6	0.79m	0.95m	-	-	0.35m
7	0.53m	0.81m	0.95m	-	0.53m
8	5.07m	5.16m	5.06m	-	4.97m
9	1.52m	1.68m	1.73m	-	1.35m
10	5.87m	5.83m	5.87m	-	5.72m
11	11.04m	11.13m	-	11.09m	10.99m
12	2.24m	2.30m	2.08m	-	-
13	3.76m	4.09m	4.05m	-	2.74m
14	4.10m	4.11m	4.00m	-	2.51m
15	5.45m	5.56m	5.79m	-	4.65m
16	1.70m	1.91m	2.06m	-	1.64m
17	2.90m	2.72m	-	2.85m	1.80m
18	8.05m	-	-	-	-
19	1.21m	1.35m	1.52m	-	0.69m
20	8.45m	8.41m	8.44m	-	8.57m
21	2.77m	2.86m	-	2.60m	2.01m
22	0.78m	1.09m	1.26m	-	1.01m
23	11.07m	11.13m	-	-	-

Water Levels in the Piezometers

Date: 1977	1A Depth[1]	1B Height[2]	2A Depth	2B Height	3A Depth	3B Height
Aug 10	1.22m	-	8.91m	-	1.95m	-
Aug 16	1.22m	-	8.20m	-	1.88m	-
Aug 23	1.29m	-	8.82m	-	1.93m	-
Aug 30	1.35m	-	9.00m	-	2.10m	-
Sep 6	1.37m	-	9.04m	-	2.05m	-
Sep 14	1.32m	-	8.63m	-	1.89m	-
Sep 20	1.35m	-	8.95m	-	1.85m	-
Sep 27	1.33m	-	8.92m	-	1.84m	-
Oct 4	1.31m	-	8.87m	-	1.83m	-
Oct 18	1.31m	3.5m	8.79m	-	1.84m	11.3m
Oct 26	1.33m	2.1m	8.78m	7.1m	1.85m	11.3m
Nov 1	1.33m	2.5m	8.79m	7.1m	2.09m	11.3m
Nov 8	1.32m	2.5m	8.78m	7.1m	2.06m	11.3m
Nov 15	1.37m	2.7m	8.63m	7.1m	2.02m	10.6m
Nov 22	1.61m	2.8m	8.87m	7.1m	2.07m	10.6m
Nov 30	1.73m	4.2m	8.71m	8.3m	2.06m	11.3m
Dec 7	1.62m	-	8.70m	7.1m	2.16m	F
Dec 21	1.99m	2.8m	8.79m	7.8m	2.19m	F
1978						
Jan 3	2.01m	3.5m	8.87m	-	2.20m	F
Jan 10	2.09m	2.8m	8.86m	6.7m	2.24m	F
Jan 25	2.08m	2.8m	8.87m	7.1m	2.23m	F
Feb 13	2.19m	F	8.87m	7.1m	2.22m	F
Mar 8	2.22m	F	8.90m	7.1m	2.21m	F
Apr 26	2.02m	F	8.87m	7.1m	2.18m	F
Jun 27	1.57m	3.5m	8.87m	7.1m	2.07m	-
Jul 25	1.65m	3.5m	8.86m	7.1m	2.10m	-

[1]: depth below ground surface
[2]: height above ground surface
F: water in piezometer was frozen

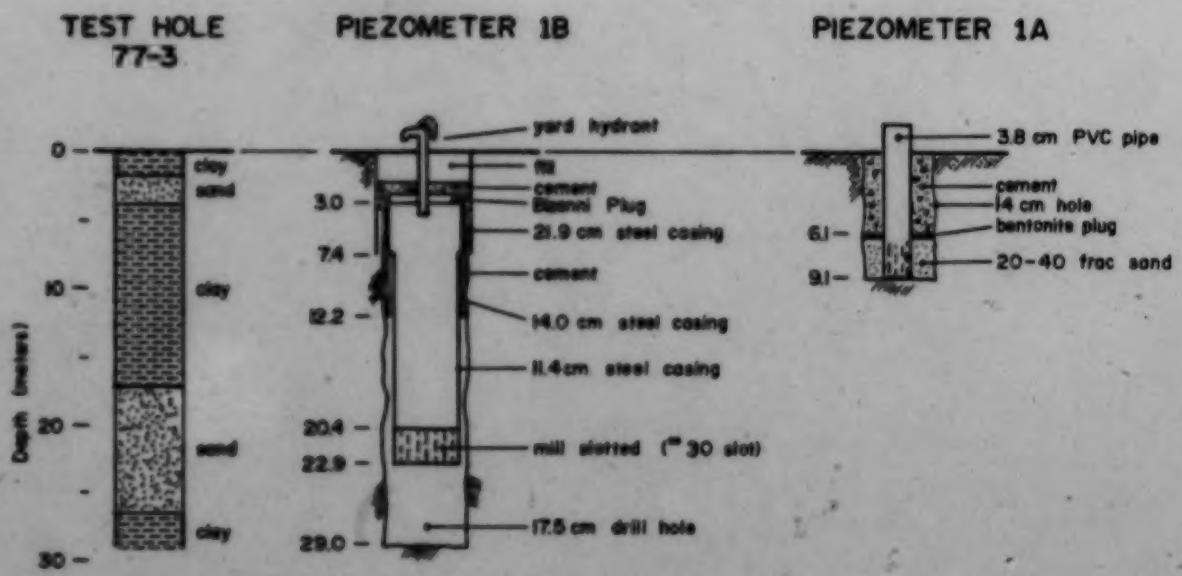


Figure 31. Piezometer details, nest #1.

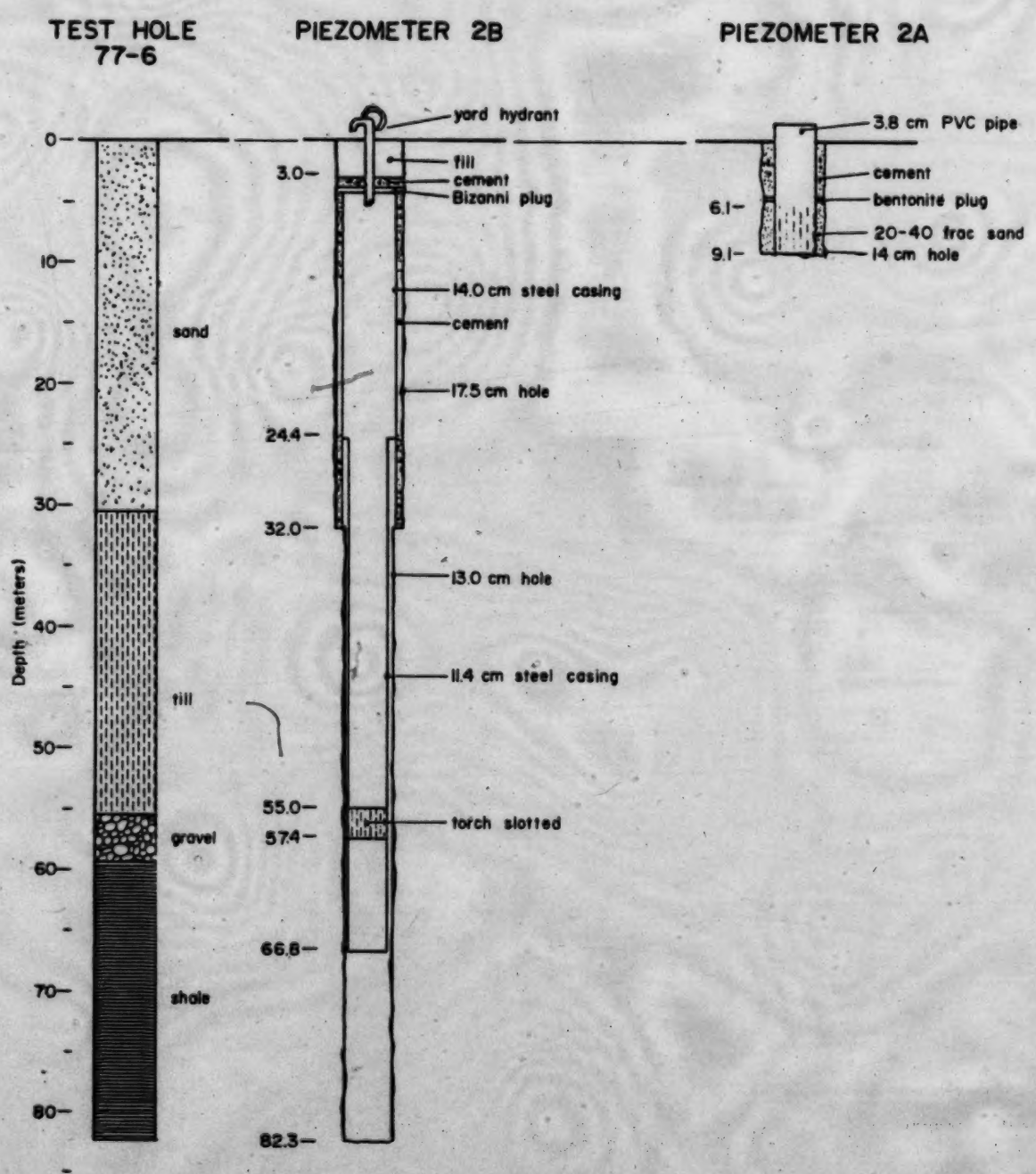


Figure 32. Piezometer details, nest #2.

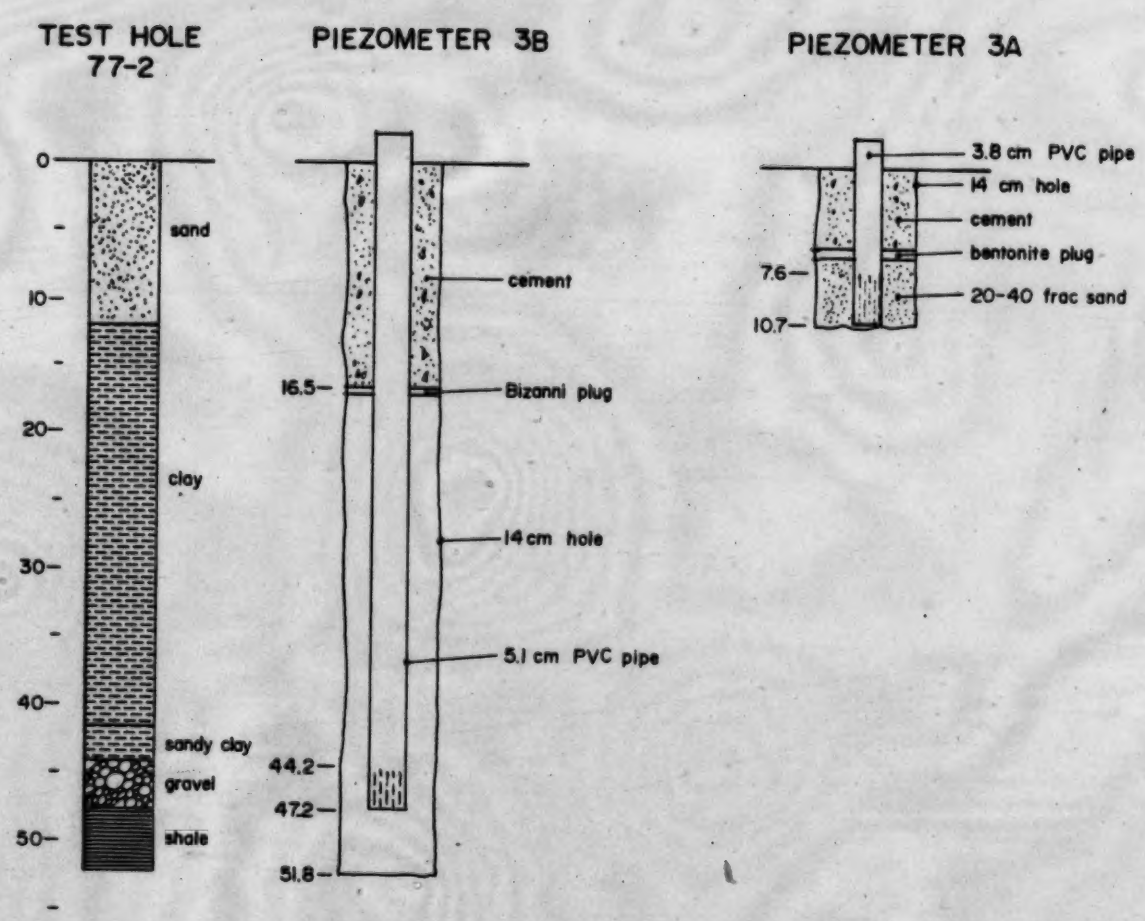


Figure 33. Piezometer details, nest #3.

Aquifer Test: Piezometer 1B

LSD 4-15-67-24-W4M

Date test started: July 29, 1977
Pre-test water level: flowing; static is 1.67m above ground
Test-hole depth: 29.0m
Average test rate: 14 L/min
Depth to top of aquifer: 17.4m
Screen set at: 20.4m to 22.9m
Pumping interval: 51 min
Datum point: top of casing; (+0.43m)

pumping interval

Time (t) since pumping started	Depth to water	Drawdown (s)
1 min	0.94m	2.61m
2 min	1.52m	3.19m
3 min	2.06m	3.73m
4 min	2.62m	4.29m
5 min	3.19m	4.86m
6 min	3.44m	5.11m
7 min	3.86m	5.33m
8 min	4.40m	6.07m
9 min	5.11m	6.78m
10 min	5.38m	7.05m
15 min	8.09m	9.76m
20 min	10.37m	12.04m
25 min	13.08m	14.75m
30 min	15.75m	17.42m
40 min	20.93m	22.60m
51 min	-	-

recovery interval
piezometer 1B

Time (t) since pumping stopped	Depth to water	Residual drawdown (s')	Ratio t/t'
1 min	19.51m	21.18m	52.00
2 min	18.39m	20.06m	26.50
3 min	17.50m	19.17m	18.00
4 min	16.74m	18.41m	13.75
5 min	16.19m	17.86m	11.20
6 min	15.67m	17.34m	9.50
7 min	15.19m	16.86m	8.29
8 min	14.63m	16.30m	7.38
9 min	14.10m	15.77m	6.68
10 min	13.58m	15.25m	6.10
15 min	11.76m	13.43m	4.40
20 min	9.91m	11.58m	3.55
25 min	-	-	-
30 min	7.15m	8.82m	2.70
40 min	4.33m	6.00m	2.28
50 min	3.05m	4.72m	2.20
60 min	1.78m	3.45m	1.85
75 min	0.37m	2.04m	1.68

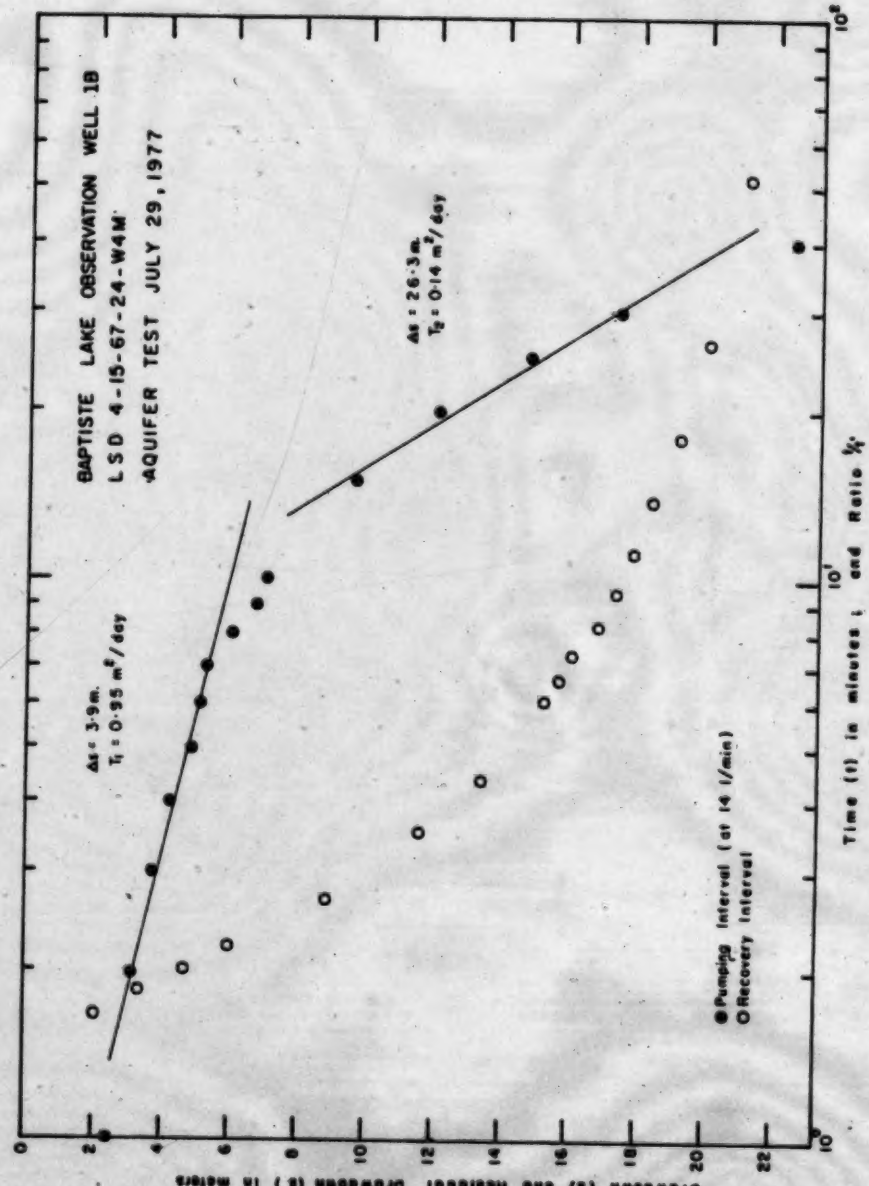

BAPTISTE LAKE OBSERVATION WELL 1B
LSD 4-15-67-24-W4M
AQUIFER TEST JULY 29, 1977
Δs = 3·9m.
T1 = 0·55 m²/day
Δs = 26·3m.
T2 = 0·14 m²/day
●Pumping Interval (at 14 l/min)
○Recovery Interval
Drawdown (s) and Residual Drawdown (s') in metres
Time (t) in minutes ; and Ratio t/t'

Figure 34. Aquifer test, piezometer 1B.

Aquifer Test: Piezometer 2B

LSD 1-21-66-24-W4M

Date test started: July 28, 1977
Pre-test water level: flowing; static is 6.8m above ground
Test-hole depth: 82.3m
Average test rate: 35 L/min
Depth to top of aquifer: 55.8m
Screen set at: 55.0m to 51.4m
Pumping interval: 20 min
Datum point: top of casing; (+0.3m)

pumping interval
test #1

Time (t) since pumping started	Depth to water	Drawdown (s)
1 min	2.92m	7.72m
2 min	4.57m	11.37m
3 min	6.45m	13.85m
4 min	8.38m	15.18m
5 min	10.08m	16.88m
6 min	11.68m	18.48m
7 min	13.26m	20.06m
8 min	14.68m	21.48m
9 min	16.08m	22.88m
10 min	17.22m	24.02m
15 min	22.73m	29.53m
20 min	-	-

recovery interval
piezometer 1B, test #1

Time (t) since pumping stopped	Depth to water	Residual drawdown (s')	Ratio t/t'
1 min	21.56m	28.36m	21.00
2 min	20.27m	27.07m	11.00
3 min	19.25m	26.05m	7.66
4 min	18.16m	24.96m	6.00
5 min	16.94m	23.74m	5.00
6 min	15.77m	22.57m	4.33
7 min	15.04m	21.84m	3.86
8 min	14.15m	20.95m	3.50
9 min	13.21m	20.01m	3.22
10 min	12.32m	19.12m	3.00
15 min	8.06m	14.86m	2.33
20 min	4.32m	11.12m	2.00
25 min	1.98m	8.78m	1.80
30 min	0.00m	6.80m	1.67

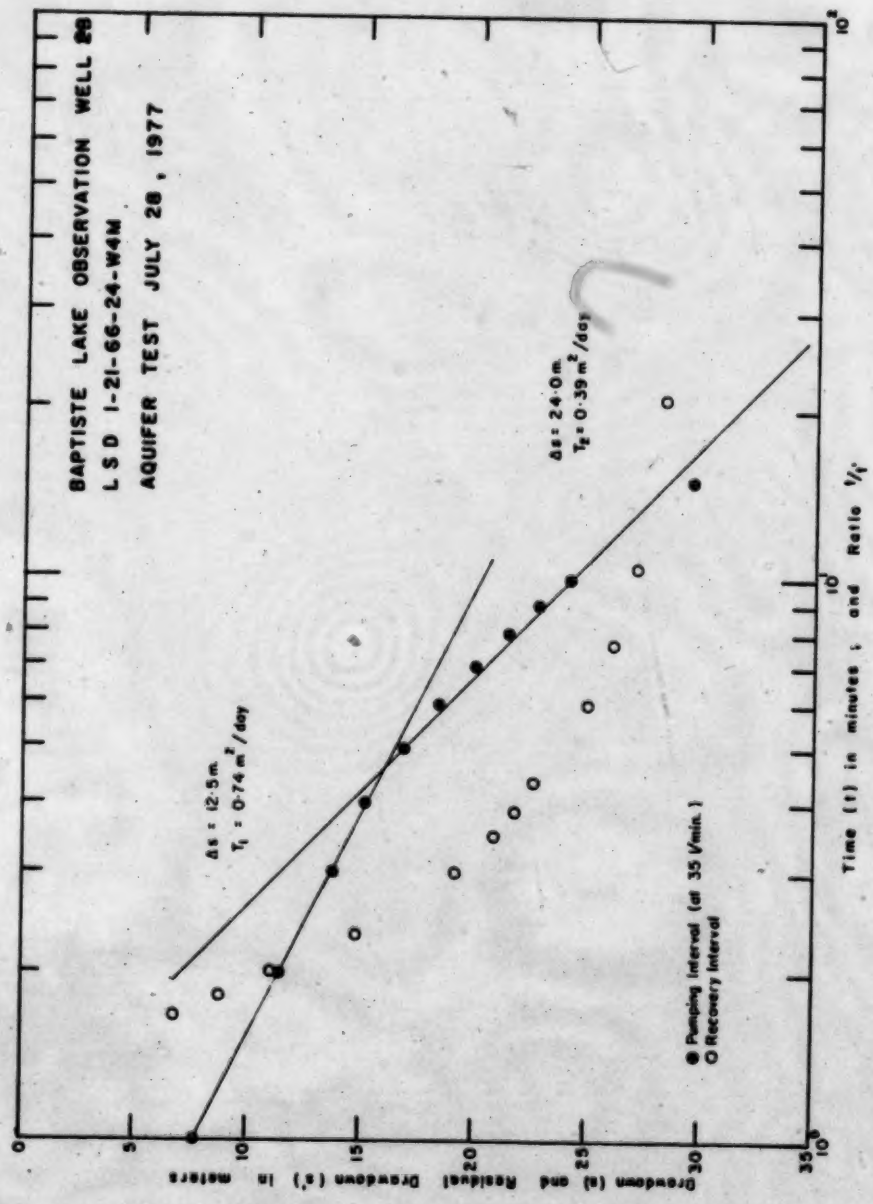


Figure 35. Aquifer test no. 1, piezometer 28.

Aquifer Test: Piezometer 2B

LSD 1-21-66-24-W4M

Date test started: July 28, 1977
Pre-test water level: flowing; static is 6.8m above ground
Test-hole depth: 82.3m
Average test rate: 18 L/min
Depth to top of aquifer: 55.8m
Screen set at: 55.0m to 51.4m
Pumping interval: 90 min
Datum point: top of casing; (+0.3m)

pumping interval
piezometer 2B, test #2

Time since pumping started	Depth to water	Drawdown (s)
1 min	1.52m	8.32m
2 min	2.31m	9.11m
3 min	3.39m	10.19m
4 min	4.34m	11.14m
5 min	5.23m	12.03m
6 min	6.10m	12.90m
7 min	6.78m	13.58m
8 min	7.62m	14.42m
9 min	8.36m	15.16m
10 min	8.99m	15.79m
15 min	11.92m	18.72m
20 min	13.99m	20.79m
25 min	15.79m	22.59m
30 min	17.60m	24.40m
40 min	19.20m	26.00m
50 min	20.22m	27.02m
75 min	19.18m	25.98m
90 min	24.08m	30.88m

recovery interval
piezometer 2B, test #2

time (t) since pumping stopped	Depth to water	Residual drawdown (s')	Ratio t/t'
1 min	21.72m	28.52m	91.00
2 min	20.37m	27.17m	46.00
3 min	19.20m	26.00m	31.00
4 min	17.98m	24.78m	23.50
5 min	16.89m	23.69m	19.00
6 min	15.83m	22.63m	16.00
7 min	14.83m	21.63m	13.86
8 min	-	-	-
9 min	12.96m	19.76m	11.00
10 min	12.09m	18.89m	10.00
15 min	7.70m	14.50m	7.00
20 min	4.80m	11.60m	5.50
25 min	2.32m	9.12m	4.60
30 min	0.02m	6.82m	4.00
40 min	0.00m	6.80m	3.25

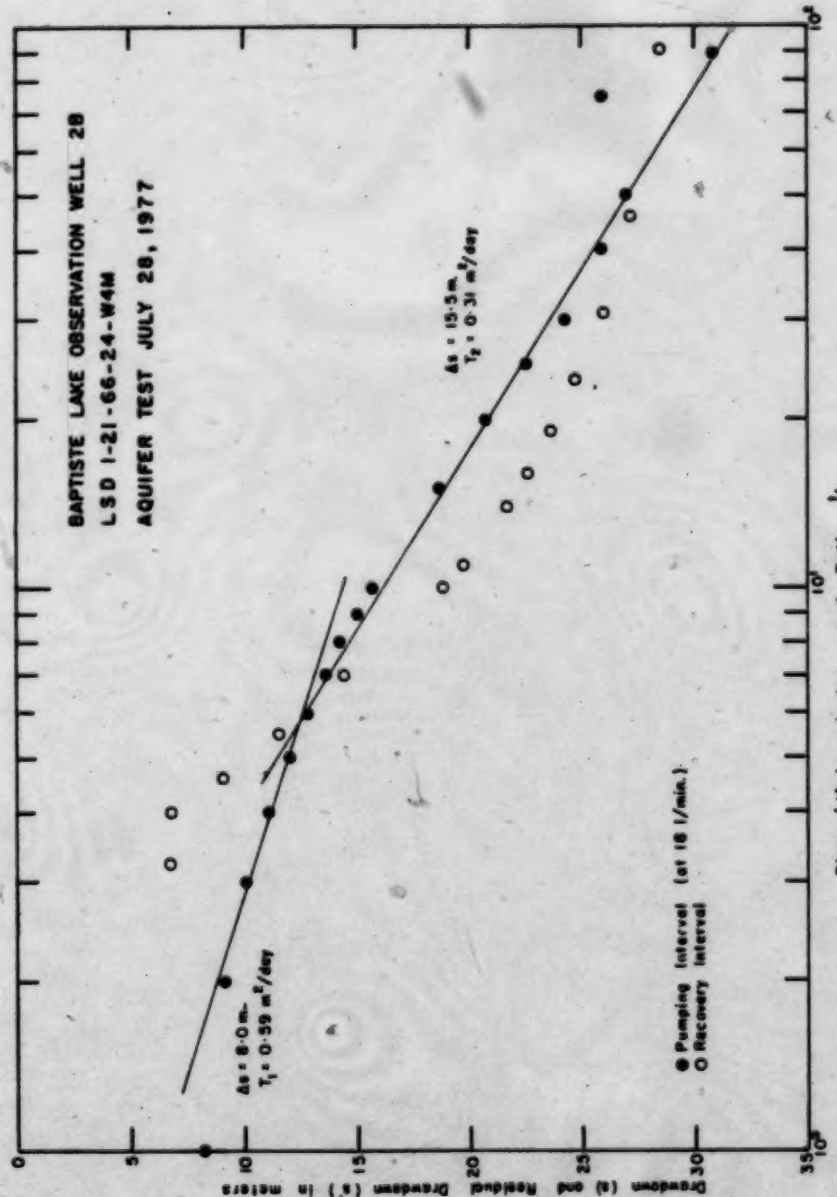

BAPTISTE LAKE OBSERVATION WELL 28
LSD 1-21-66-24-W4M
AQUIFER TEST JULY 28, 1977
Δs = 8·0 m
T1 = 0·59 m²/day
Δs = 15·5 m
T2 = 0·31 m²/day
● Pumping interval (at 18 l/min.)
○ Recovery interval
Drawdown (s) and Residual Drawdown (s') in metres
Time (t) in minutes ; and Ratio t/t'

Figure 36. Aquifer test no. 2, piezometer 28.

APPENDIX IX

LITHOLOGIC LOGS OF THE TEST-HOLES

Lithology Logs of the Shallow Test-Holes

SITE #1

SE of LSD 1-26-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	silt	sandy, stoney, light brown.
1.5 - 3.7	till	clayey, dark brown.
3.7 - 4.6	till	clayey, moist, dark grey-brown.
4.6 - 6.1	till	as above but with greater proportions of clay.
6.1 - 7.6	till	sandy, light grey, water at 6.4m.

SITE #2

SW of LSD 3-26-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 3.7	clay	moist, mottled, light yellow to medium brown.
3.7 - 5.2	till	very clayey, some stones, moist, dark grey.
5.2 - 6.1	till	sandy, light grey, water at 5.2m.

SITE #3

SW of LSD 16-27-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 0.9	sand	clayey, rusty-brown.
0.9 - 2.1	clay	moist, grey-brown.
2.1 - 4.6	sand	medium grained, well sorted, oxidized where saturated, rusty-brown, water at 2.6m.

SITE #4

SW of LSD 6-22-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 0.6	till	very sandy, medium grained, orange-brown.
0.6 - 1.5	till	mottled, yellow and brown bands.
1.5 - 3.0	till	clayey, grey-brown, water at 1.5m.
3.0 - 4.6	till	same as above but dark-grey.

SITE #5

SE of LSD 5-22-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 0.9	till	very clayey, moist, dark grey-brown.
0.9 - 7.6	till	very clayey, moist, wet sand layer at 3.7m, dark grey, water at 6.4m.

SITE #6

NE of LSD 7-21-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	till	silty, moist, grey-brown, water at 0.9m.
1.5 - 3.0	till	sandy, grey.

SITE #7

SW of LSD 10-21-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	till	very sandy, layers of rusty-brown, grey, purple colours, water at 0.6m.
1.5 - 2.4	sand	fine to medium grained, brown.
2.4 - 3.0	sand	fine to medium grained, dark grey.

SITE #8

SW of LSD 12-21-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 2.1	sand	medium to coarse grained, very stoney, moist, rusty-orange.
2.1 - 3.4	sand	fine to medium grained, moist, dull brown.
3.4 - 6.1	sand	medium grained, well sorted, moist, rusty-orange, water at 4.6m.

SITE #9

SE of LSD 2-28-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 2.7	silt	very mottled, clay-loam texture, some oxidized areas, dark grey.
2.7 - 4.6	sand	fine to medium grained, buff-yellow, water at 2.7m.

SITE #10

SW of LSD 4-28-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 2.1	sand	medium grained, well sorted, orange-yellow.
2.1 - 7.6	sand	medium grained, well sorted, buff-yellow, water at 6.7m.
7.6 - 9.1	sand	medium grained, slightly clayey, buff-yellow.

SITE #11

SW of LSD 4-33-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 7.6	till	very clayey and sandy, moist, grey-brown.
7.6 - 12.2	till	very clayey, dark grey, water at 11.6m.
12.2 - 13.7	till	very sandy, light grey.

SITE #12

NW of LSD 9-28-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.8	sand	medium grained, well sorted, dry rusty-orange.
1.8 - 3.0	sand	medium grained, well sorted, rusty-brown, water at 1.8m.

SITE #13

SW of LSD 8-33-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	silt	oxidized, sandy, yellow-brown.
1.5 - 4.0	clay	grey-brown.
4.0 - 12.2	till	very clayey, dark grey, water at 11.0m.

SITE #14

NE of LSD 1- 3-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 7.0	till	very clayey, sandy near the surface, moist, dark brown.
7.0 - 10.7	till	very clayey, dark grey, water at 9.5m.

SITE #15

SW of LSD 16- 3-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 0.6	sand	light brown.
0.6 - 2.4	till	sandy, wet, white.
2.4 - 6.4	till	very clayey, oxidized, very wet, dark brown.
6.4 - 9.1	till	very clayey, dark grey, water at 7.9m.

SITE #16

NE of LSD 15-10-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	sand	medium grained, well sorted, dry, buff-yellow.
1.5 - 4.6	sand	medium grained, well sorted, wet, slightly clayey, buff-yellow, water at 3.0m.

SITE #17

NE of LSD 8-15-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	till	sandy, dry, dark brown.
1.5 - 3.0	till	mottled, oxidized areas, wet, dark brown.
3.0 - 4.6	till	very clayey, wet, dark grey-brown.
4.6 - 12.2	till	very clayey, wet, dark grey, water at 11.0m.

SITE #18

NW of LSD 10-11-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	till	very clayey, sandy at the surface, grey-brown.
1.5 - 6.1	till	very clayey, moist, grey-brown.
6.1 - 7.6	till	very clayey, moist, dark grey.
7.6 - 10.7	till	very clayey, moist, slightly more slity than above, dark grey, water at 10.1m.

SITE #19

SW of LSD 4-13-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	till	sandy, moist, yellow-brown.
1.5 - 3.0	till	sandy, wet, yellow-brown.
3.0 - 4.6	till	sandy, moist, yellow-brown.
4.6 - 6.1	till	very clayey, dark grey-brown, water at 4.6m.

SITE #20

NW of LSD 4-12-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 2.7	till	clayey, dry, oxidized,calcareous deposits, yellow-brown.
2.7 - 4.6	till	very clayey, moist, dark grey-brown.
4.6 - 15.2	till	very clayey, moist, dark grey-brown, water at 14.3m.

SITE #21

NE of LSD 16-34-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.8	sand	medium grained, well sorted, yellow-orange.
1.8 - 4.6	till	very clayey, moist, yellow-brown.
4.6 - 6.1	till	very clayey, moist, grey-brown.
6.1 - 7.3	till	very clayey, moist, dark grey.
7.3 - 7.6	till	very clayey, sandy, dark grey, water at 7.3m.
7.6 - 9.1	till	sandy, light grey.

SITE #22

NW of LSD 2- 2-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	sand	medium grained, clayey, light grey, water at 0.9m.
1.5 - 3.0	sand	clayey, light grey-brown.

SITE #23

SW of LSD 11-35-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 2.1	silt	clayey, dry, orange-brown.
2.1 - 5.2	till	mottled, moist, stoney, dark brown.
5.2 - 6.1	till	very clayey, moist, stoney, dark grey.
6.1 - 9.8	till	very clayey, moist, dark grey.
9.8 - 12.2	till	sandy, moist, grey-brown, water at 10.7m.

SITE #24

NE OF LSD 16-17-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 6.1	till	very clayey, moist, dark brown.
6.1 - 15.2	till	very clayey, moist, dark grey.

* no water *

SITE #25

NW of LSD 14-28-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 3.0	till	some stones, alternating moist and dry layers, dark brown.
3.0 - 6.7	till	as above but no stones.
6.7 - 9.1	till	dark grey-brown, water at 8.2m.

Lithology Logs of the Deep Test-Holes

TEST-HOLE 76-1

LSD 4-15-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 7.6	silt	sandy, few pebbles, dark green.
7.6 - 7.7	gravel	
7.7 - 21.3	clay	sandy, few pebbles, dark green.
21.3 - 24.4	till	silty and sandy, dark green.
24.4 - 25.9	till	silty and sandy, taking water, dark green.
25.9 - 29.8	sand	
29.8 - 38.1	till	sandy, dark green.
38.1 - 39.6	sand	
39.6 - 42.1	till	sandy, with pebbles, dark green.
42.1 - 43.0	gravel	composed of shale and ironstone fragments, some clay, quartz pebbles fairly rounded, 5 cm in diameter.
43.0 - 54.9	shale	dark grey-green.

TEST-HOLE 76-2

LSD 1-20-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 29.9	sand	oxidized on top, few pebbles, coal fragments, green-grey.
29.9 - 44.2	till	sandy, coal fragments, very clayey in top 1.5m, pebbles and thin gravel layers, green-grey.
44.2 - 57.9	till	as above but with slightly more gravel.
57.9 - 61.3	till	sandy, contains hard shale fragments and ironstone fragments, possible flowing zone, reddish-brown.
61.3 - 64.3	till	as above but harder drilling.
64.3 - 73.8	till	contains shale and ironstone fragments, reddish-brown.
73.8 - 79.6	sand	very silty, some coal, taking water.
79.6 - 80.5	sand	
80.5 - 85.3	sand	very silty, some coal, few bedrock fragments, taking water.
85.3 - 91.4	sand	very silty, contains coal chips, taking water.
91.4 - 93.9	till	sandy.
93.9 - 97.8	till	very clayey, contains some fine gravel.
97.8 - 98.1	till	as above but with coal chips.
98.1 -102.1	shale	dark grey-green.

TEST-HOLE 76-3

LSD 13-35-66-24-W4M

Depth (m)	Sediment	Descrpition
0.0 - 12.2	silt	oxidized, very sandy, quite a few pebbles, medium grained sand, brown.
12.2 - 36.6	till	sandy.
36.6 - 40.2	sand	silty.
40.2 - 41.1	till	very clayey, contains pebbles.
41.1 - 56.7	shale	dark grey-green.

TEST-HOLE 76-4

LSD 12-26-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 5.5	sand	medium grained, brown.
5.5 - 20.1	till	sandy, dark green.
20.1 - 36.6	shale	dark grey-green.

TEST-HOLE 76-5

LSD 12-36-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 54.9	till	sandy, contains pebbles, dark green.
54.9 - 57.9	till	as above but with coal chips.
57.9 - 62.5	till	sandy, contains pebbles.
62.5 - 73.2	shale	dark grey-green.

TEST-HOLE 76-8

LSD 13-33-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 20.4	till	sandy, few pebbles, green-grey.
20.4 - 30.5	shale	dark grey-green.

TEST-HOLE 76-11

LSD 14-12-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 7.6	till	sandy, with pebbles.
7.6 - 42.7	shale	dark grey-green.

TEST-HOLE 77-1

LSD 6-21-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 1.5	sand	fine grained, some coal chips, reddish-brown.
1.5 - 5.8	sand	fine grained, some coal chips, grey.
5.8 - 6.7	sand	medium grained, black.
6.7 - 9.5	sand	medium grained, coal chips, grey.
9.5 - 11.9	clay	contains alot of organic material, dark grey.
11.9 - 12.5	sand	medium grained, lost circulation, dark grey.
12.5 - 17.1	clay	no pebbles, grey.
17.1 - 22.8	shale	soft, grey-green.

TEST-HOLE 77-2

LSD 6-21-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 2.4	sand	medium to coarse grained, oxidized.
2.4 - 12.2	sand	fine grained, contains wood, shells and coal chips, grey.
12.2 - 13.7	clay	dark brown.
13.7 - 19.2	clay	black.
19.2 - 41.1	clay	grey.
41.1 - 44.2	till	sandy.
44.2 - 47.2	gravel	medium grained, salt and pepper texture, taking water.
47.2 - 51.8	shale	dark grey-green.

TEST-HOLE 77-3

LSD 4-15-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 2.1	silt	sandy, no pebbles, grey.
2.1 - 4.3	sand	medium grained, grey.
4.3 - 17.4	clay	no pebbles, grey.
17.4 - 26.8	sand	fine to medium grained, grey, taking water.
26.8 - 29.0	till	sandy, grey.

TEST HOLE 77-4

LSD 7-10-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 3.1	clay	oxidized, some pebbles, brown.
3.1 - 11.3	till	very clayey, grey.
11.3 - 13.1	till	oxidized, grey.
13.1 - 19.8	shale	dark grey-green.

TEST-HOLE 77-5

LSD 8-10-67-24-W4M

Depth (m)	Sediment	Description
0.0 - 3.4	clay	oxidized, some pebbles, brown.
3.4 - 7.9	clay	grey.
7.9 - 8.2	gravel	very silty.
8.2 - 14.0	till	very clayey, grey.
14.0 - 14.6	gravel	silty, some coal fragments.
14.6 - 27.4	shale	dark grey-green.

TEST-HOLE 77-6

LSD 1-20-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 30.5	sand	
30.5 - 55.8	till	
55.8 - 59.4	gravel	silty, feldspar and quartz fragments.
59.4 - 82.3	shale	dark grey-green.

HUTTERIAN BRETHREN COLONY WELL

SE-36-66-24-W4M

Depth (m)	Sediment	Description
0.0 - 3.1	clay	oxidized.
3.1 - 7.6	clay	grey.
7.6 - 12.2	till	soft, grey.
12.2 - 12.8	clay	oxidized.
12.8 - 19.8	till	grey.
19.8 - 21.3	till	silty, grey.
21.3 - 36.6	silt	calcareous, grey.
36.6 - 38.7	sand	interbedded with silt.
38.7 - 42.7	silt	calcareous, grey.
42.7 - 45.1	clay	hard, non-calcareous, grey.
45.1 - 50.0	silt	soft, grey.
50.0 - 52.4	clay	
52.4 - 55.2	sand	
55.2 - 67.1	shale	

* drilled and logged by Elk Point Drilling Ltd on 69/09/06.
* static water level is 31.5 m below ground surface.

APPENDIX X

CLIMATIC DATA

Precipitation, Athabasca 2 meteorlogy station
(all values in cm)

Month	1970	1971	1972	1973	1974	1975	1976	1977
Jan	2.41	5.89	2.77	0.51	5.61	2.64	1.42	1.86
Feb	1.73	0.91	5.31	2.77	3.53	1.04	1.85	0.89
Mar	5.49	2.29	3.61	0.36	3.87	1.73	2.01	2.53
Apr	0.23	2.49	2.31	3.12	4.98	2.41	0.41	1.73
May	1.79	1.68	2.72	8.33	2.31	2.54	3.35	11.25
Jun	15.32	12.75	11.40	9.40	2.90	9.78	6.86	6.10
Jul	12.73	10.69	5.76	5.18	17.42	13.31	8.79	19.34
Aug	4.98	6.15	3.58	7.09	5.08	11.74	9.50	5.46
Sep	3.53	1.60	3.30	7.26	6.10	2.34	2.72	5.97
Oct	3.63	1.19	1.19	4.75	1.04	1.65	3.15	1.50
Nov	1.19	2.90	2.03	6.12	1.06	0.61	0.56	0.97
Dec	3.45	3.48	2.08	4.83	1.91	4.34	4.24	1.73

Temperature, Athabasca 2 Meteorology Station
(all values in °C)

Month	1970	1971	1972	1973	1974	1975	1976	1977
Jan	-19.1	-22.2	-20.5	-12.9	-21.1	-13.6	-12.3	-14.4
Feb	-7.3	-9.6	-17.7	-10.9	-10.7	-14.7	-9.3	-0.9
Mar	-8.1	-7.6	-5.3	-2.1	-11.1	-8.8	-5.0	-3.9
Apr	3.4	3.4	1.1	3.1	4.0	0.7	6.5	6.6
May	10.0	12.6	11.8	11.6	8.1	9.6	11.3	11.5
Jun	16.6	14.1	14.2	13.6	14.8	13.2	12.8	14.8
Jul	16.1	15.7	14.0	16.2	14.9	17.8	16.9	14.4
Aug	15.1	16.6	16.3	14.6	12.4	12.5	16.7	12.4
Sep	9.2	8.8	5.5	9.4	8.3	10.9	12.4	9.5
Oct	2.9	3.8	1.8	4.1	6.5	3.6	3.5	5.2
Nov	-9.5	-6.4	-4.9	-14.1	-3.7	-5.2	-2.1	-6.9
Dec	-20.3	-18.6	-17.7	-14.8	-6.0	-13.3	-10.6	-17.8

Potential Evaporation, Thornthwaite's Method
(all values in cm)

Month	1970	1971	1972	1973	1974	1975	1976	1977
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apr	2.60	2.60	1.08	2.48	3.25	6.97	4.41	4.47
May	8.02	9.75	9.63	9.25	7.01	7.99	8.71	9.18
Jun	12.69	10.97	11.40	10.73	11.84	10.60	9.89	11.59
Jul	12.65	12.30	11.53	12.77	12.13	14.01	12.68	11.56
Aug	10.80	11.69	11.84	10.56	9.42	9.25	11.62	9.16
Sep	5.80	5.51	3.93	6.00	5.60	6.90	7.34	6.04
Oct	1.77	2.17	1.32	2.40	3.77	2.25	1.93	2.99
Nov	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00